PB83-259697

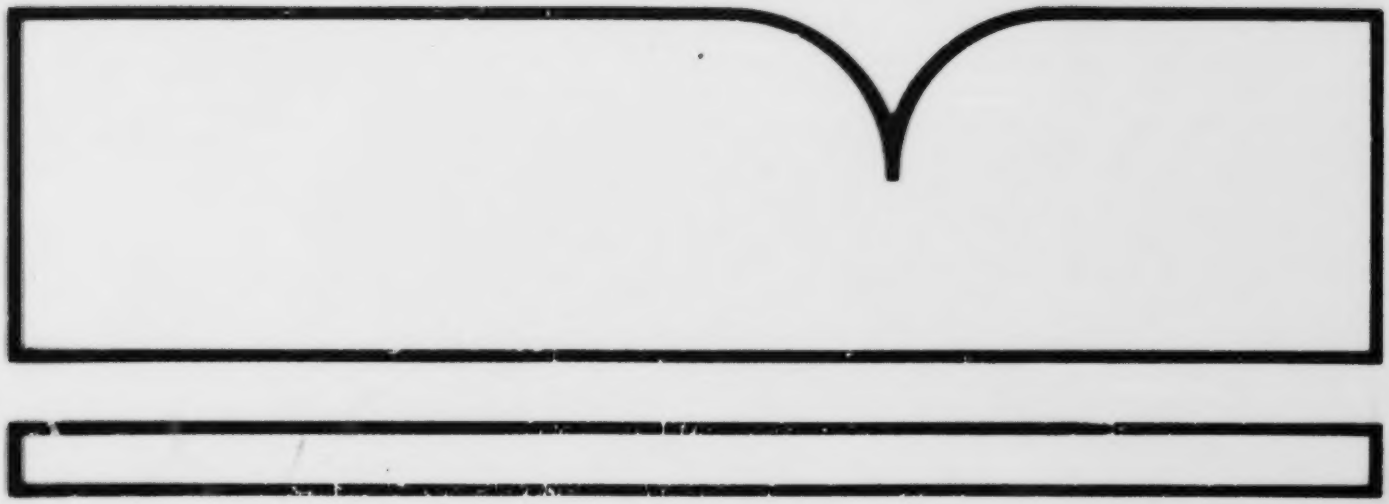
Plant-Scale Demonstration of Sludge Incinerator Fuel Reduction

Indianapolis Center for Advanced Research, IN

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Sep 83



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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-83-083		

4. TITLE AND SUBTITLE	5. REPORT DATE
PLANT-SCALE DEMONSTRATION OF SLUDGE INCINERATOR FUEL REDUCTION	September 1983
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Albert J. Verdouw, Eugene W. Waltz, Webb Bernhardt	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
City of Indianapolis Department of Public Works 2460 City County Building Indianapolis, Indiana 46204	DU B-113 PE CAZB1B B-20
	11. CONTRACT/GRANT NO.
	S806248010
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Municipal Environmental Research Laboratory--Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	Final
	14. SPONSORING AGENCY CODE
	EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Howard Wall, (513) 684-7659

16. ABSTRACT

A plant-scale demonstration was conducted on 8 sewage sludge incinerators at Indianapolis, Indiana to reduce fuel consumption. More efficient operating mode of operation was developed, instrumentation and controls were added and an operator training program was conducted to reduce fuel consumption. Over an 8-month demonstration period the fuel usage was reduced 34% for a savings of over $900,000 per year ($1.00 gal fuel). A short demonstration, when technical personnel were present at all times, indicated that the fuel savings could be 75%.

It was estimated that all plants in the U.S. could reduce 20-50% of their fuel usage if a similar program were used for sludge incineration.

Additional savings of $3,000,000 were realized for air pollution abatement equipment. Particulate emissions were sufficiently reduced so that this additional equipment was not required.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Wastewater Sludge Combustion Incineration Air Pollution Fuel Savings		07C

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to Public	Unclassified	80
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

PB83-259697

EPA-600/2-83-083
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FOREWORD

The U. S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory devleops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

Incineration is an ultimate disposal option that provides an inert, safe, minimum-volume residue that minimizes ultimate landfill requirements. This disposal method is expected to find increasing use as landfill sites become less available and as ocean disposal is phased out for environmental reasons. Incinerator auxiliary fuel requirements are of great concern because of the increasing costs of all fossil fuels. This report presents results from in-plant research to reduce fuel consumption and particulate emissions at an existing incinerator installation by improvements in incinerator instrumentation and controls, and by improved operation. Such improvements can be accomplished in a short time at very low capital costs.

Francis T. Mayo
Director
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Laboratory

ABSTRACT

A field research and demonstration project was conducted to reduce fuel consumption and particulate emissions of municipal sludge incinerators by improving instrumentation and control systems and by using more fuel-efficient incinerator operating modes. A low-capital-cost approach to achieving major fuel reduction was operationally demonstrated by the City of Indianapolis Department of Public Works at its Belmont Wastewater Treatment Plant Incineration Facility in Indianapolis, Indiana, using eight conventional multiple-hearth incinerators.

The existing incinerators were upgraded with modern instrumentation and control systems for sludge flow rate, fuel flow rate, fuel flow control, airflow control, and exhaust oxygen analysis. A more fuel efficient incinerator operating mode was developed from an extensive program of combustion engineering measurement, testing, and operational analysis. The incinerator operators were then given a training program on the new equipment and operating mode. The new operating mode with improved instrumentation and control systems was also effective in enabling the existing incinerators (equipped with low-energy, cyclonic-type scrubbers) to meet particulate emission standards.

During an 8 month, full-plant scale demonstration period of routine operations, a 34 percent fuel reduction was achieved, representing a cost avoidance of more than $900,000 per year. All eight of the incinerators also passed official particulate emission tests using the new operating mode developed. This result enabled the City to avoid more than $2 million in capital costs that would have been required to retrofit the incinerators with energy-intensive, venturi-type scrubbers.

The project demonstrated that improvements in existing incinerator equipment and optimization of incinerator operating modes are very cost effective. Results also showed the the incinerator operating mode can have a major effect on reducing particulate emissions.

This report was submitted in fulfillment of Contract No. S806248-01 by the City of Indianapolis Department of Public Works with technical assistance from the Indianapolis Center for Advanced Research, Energy Engineering and Research Division, under the sponsorship of the U. S. Evironmental Protection Agency. This report covers the period February 15, 1979, to December 31, 1981, and work was completed as of December 31, 1981.

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ACKNOWLEDGMENT

This project required a unique degree of cooperation and persistent effort from a large number of people within the City of Indianapolis Department of Public Works and the Indianapolis Center for Advanced Research (ICFAR). The authors particularly wish to acknowledge the supervision, operations, and maintenance personnel of the Liquid Waste Division and the ICFAR technicians for their contributions to this project.

SECTION 1

INTRODUCTION

The disposal of municipal sewage sludge by incineration most often requires the use of large amounts of auxiliary fuel. Increasing energy costs have made incinerator fuel consumption a major operational cost problem for many municipal operations. This project demonstrates how incinerator fuel consumption can be reduced by improving existing instrumentation and control systems and by using more fuel efficient operating modes. The City of Indianapolis Department of Public Works conducted this demonstration project at its Belmont Wastewater Treatment Plant Incineration Facility with the technical assistance of the Indianapolis Center for Advanced Research, Energy Engineering and Research Division.

The City of Indianapolis had been using over 2 million gallons of fuel oil to incinerate over 240,000 wet tons of sludge cake per year. This fuel consumption represented the largest single end-use of energy in City government operations. Fuel costs for sludge incineration had increased by 300% from 1973 to 1978. The operational downtime for the incinerators had also been averaging over 40% per year. A major portion of this downtime was for repair of incinerator rabble arms, teeth, and center shafts and the fire brick hearths caused in part by extreme operating temperatures (2000-2300^{o}F) and unsteady state operations. These operational problems faced by Indianapolis also plague many other cities that use multiple-hearth incinerators.

In July, 1977, the Department of Public Works decided to pursue the development and testing of new control techniques or methods for improving the operation of the existing incinerators. A joint pilot project between the Department of Public Works and the Indianapolis Center for Advanced Research (ICFAR) was conducted to determine and operationally verify the changes and improvements required to reduce fuel consumption and to achieve steady incinerator operation at reduced temperatures. This pilot project was conducted over a 7 month period and involved the following activities:

- A combustion engineering analysis was made of the multiple hearth incinerators.
- One incinerator was extensively instrumented to measure (a) excess air, (b) internal incinerator temperature profiles and wall temperatures, (c) pressure, temperature and air flow rates of all incinerator air supply sources and exhaust gas locations, (d) exhaust gas analysis, and (e) total and burner-specific fuel flow rates.

- Parametric experimental tests were conducted to determine the effect of the following incinerator variables on fuel consumption: (a) excess air, (b) sludge load rate, (c) sludge moisture and volatile content, (d) incinerator airflow, (e) combustion zone location, (f) incinerator temperature, (h) fuel burner settings, (i) use of rabble arm cooling air, and (j) sludge residence time. The test incinerator was set up in 35 operational test modes for which 194 "raw" data items were recorded for each mode.

- A comparative analysis was made of the analytical and experimental data to determine the relationship between specific fuel consumption and key incinerator operating variables.

- A full scale, 3 1/2 day demonstration test of a new fuel efficient operating mode was conducted on one incinerator. A 50% reduction in fuel consumption was achieved at sludge loading rates 10% higher as compared to past operational averages.

The results of this pilot demonstration project are documented in Reference 1.

In 1979, the U. S. Environmental Protection Agency, Municipal Environmental Research Laboratory agreed to sponsor this full plant scale project to improve the instrumentation and control systems on all 8 of the Indianapolis sludge incinerators and operationally demonstrate reduced fuel consumption with improved controls and operating modes.

SECTION 2

CONCLUSIONS

The principal conclusions from this in-plant research and demonstration project were the following:

- Incinerator auxiliary fuel consumption can be significantly reduced by improving existing operating control systems and using more fuel efficient operating modes.
- Fuel reductions can be easily and quickly achieved through operational mode changes alone in current incinerator facilities without having to make major or high cost equipment changes.
- The use of more fuel efficient operating modes will also reduce maintenance costs and incinerator down-time.
- Significant reductions in particulate emission loadings to the stack gas scrubbers were achieved when fuel efficient operating modes are used.
- A 34% fuel reduction was achieved over an 8 month full plant scale demonstration period representing a cost avoidance of over $900,000 per year. Limited analysis of operational data from other cities shows similar potential savings from 20 to 50% are possible.
- Costs for upgrading instrumentation and control systems and operator training totaled approximately $20,000 per incinerator with a payback period in fuel savings or cost avoidance of less than 3 months.
- The upgrading of instrumentation and controls and the use of more efficient operating modes enabled Indianapolis to save over $2 million dollars in pollution control costs.

SECTION 3

RECOMMENDATIONS

- Most municipal sludge incinerator operations are still experiencing high fuel consumption rates as a result of using improper incinerator operating modes. Technical investigations of incinerator operating modes should be undertaken to identify inefficient practices, instrumentation and control inadequacies, and special operator training needs which can be corrected cost effectively to achieve significant fuel savings.

- Operational tests are critically needed to further verify the interrelationship of incinerator operating modes with particulate emissions and pollution control equipment. Such tests are essential to correct a serious void that currently exists in the analytical and operational understanding of how incinerator operating modes affect particulate emissions. This information would help municipal operators comply with incinerator particulate emission standards.

- Operational tests should be conducted to determine the effect of fuel efficient operating practices on hydrocarbon or odor emissions. The use of fuel efficient operating modes is expected to eliminate the need for costly afterburning for hydrocarbon or odor control.

- Current static thermal equilibrium models of incinerator operations used for design purposes are inadequate for optimizing key incinerator operating variables. A model should be developed based on a more kinetic operational understanding of how key incinerator operating variables affect fuel consumption rates.

SECTION 4

INDIANAPOLIS INCINERATOR SYSTEM DESCRIPTION

FILTRATION SYSTEM

Indianapolis provides primary and secondary wastewater treatment for more than 610 million liters (160 million gallons) of wastewater per day and generates more than 218,000 metric tons (240,000 tons) of wet sludge cake per year. The mixed primary and secondary (waste-activated) sludge is dewatered by vacuum filtration. Incinerator ash is recycled into the sludge to reduce sludge cake moisture and to improve cake release from the vacuum filter cloth. Polymer conditioning is used to obtain solids flocculation for vacuum filtration. Although the Indianapolis sludge cake is relatively dry, the volatile content is low because of the recycled ash. Table 1 and Figure 1 compare sludge cakes from Indianapolis and several other cities. By comparison, the Indianapolis cake moisture and volatiles are lower than other cities because of the ash recycling. The key parameter that affects incinerator auxiliary fuel requirements is the ratio of cake moisture to volatile solids by weight (M/V). Figure 1 shows that the M/V ratio is not changed by the ash recycling. No significant fuel consumption impact would therefore be expected from the Indianapolis ash recycling. The Indianapolis sludge cake absolute volatile content is 17% lower than average, which represents a loss in incinerator capacity because of the recycled ash at constant cake feed rate. But this capacity reduction may be eliminated by running at higher load rates to impose the same water load on the incinerator that is experienced by no-ash-recycle systems in other cities.

INCINERATOR SYSTEM AND CONTROLS

Like most other cities using incineration for sludge disposal, Indianapolis uses multiple-hearth type incinerators. The City has eight Nichols incinerators. The incinerators are 6.78 m (22.3 feet) in diameter, 10.3 m (33.7 feet) in height. Each incinerator has eight ceramic hearths. The design load rate is 6.4 metric tons (7.0 tons) of wet sludge cake per hour. The Indianapolis incinerator system is shown schematically in Figure 2.

The following describes the original equipment and controls that were in use prior to the improvements accomplished on this project. Sludge cake enters the incinerator through a top mounted drop chute. The sludge cake is moved down through the incinerator, from hearth to hearth, by rabble arms with raking teeth connected to a rotating center shaft. The sludge cake dries in the upper hearths by exposure to the high temperature combus-

TABLE 1 - SLUDGE FILTER CAKE COMPARISON

	Typical Indpls.	Detroit	Nashville	St. Paul	St. Louis	Fairfax County	Average
Moisture (Wt %)	65	77	82.8	73	72	80	77
Volatile (Wt % of Solids)	30	50	62.2	48	56	60	55
Volatile (Absolute Wt %)	10.5	11.5	10.7	13	15.7	12	12.6
Moisture/Absolute Volatile	6.2	6.7	7.7	5.6	4.6	6.7	6.1

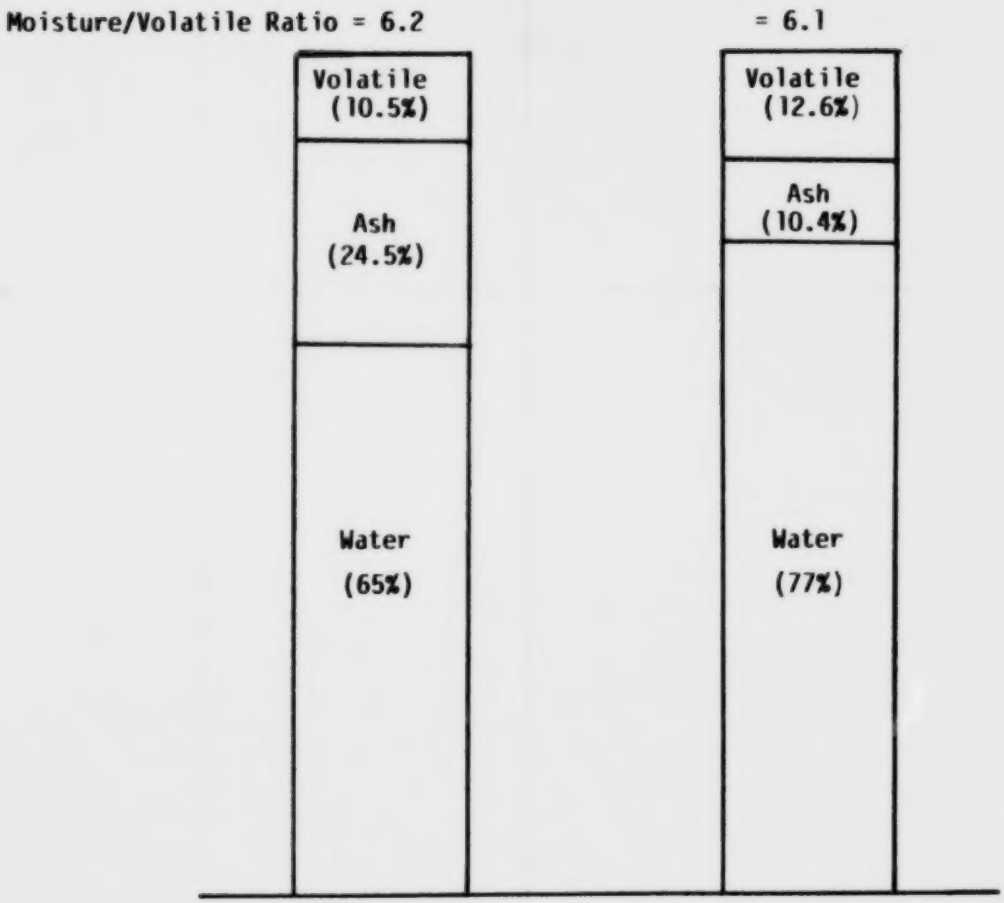

Figure 1. Sludge Filter Cake Comparison

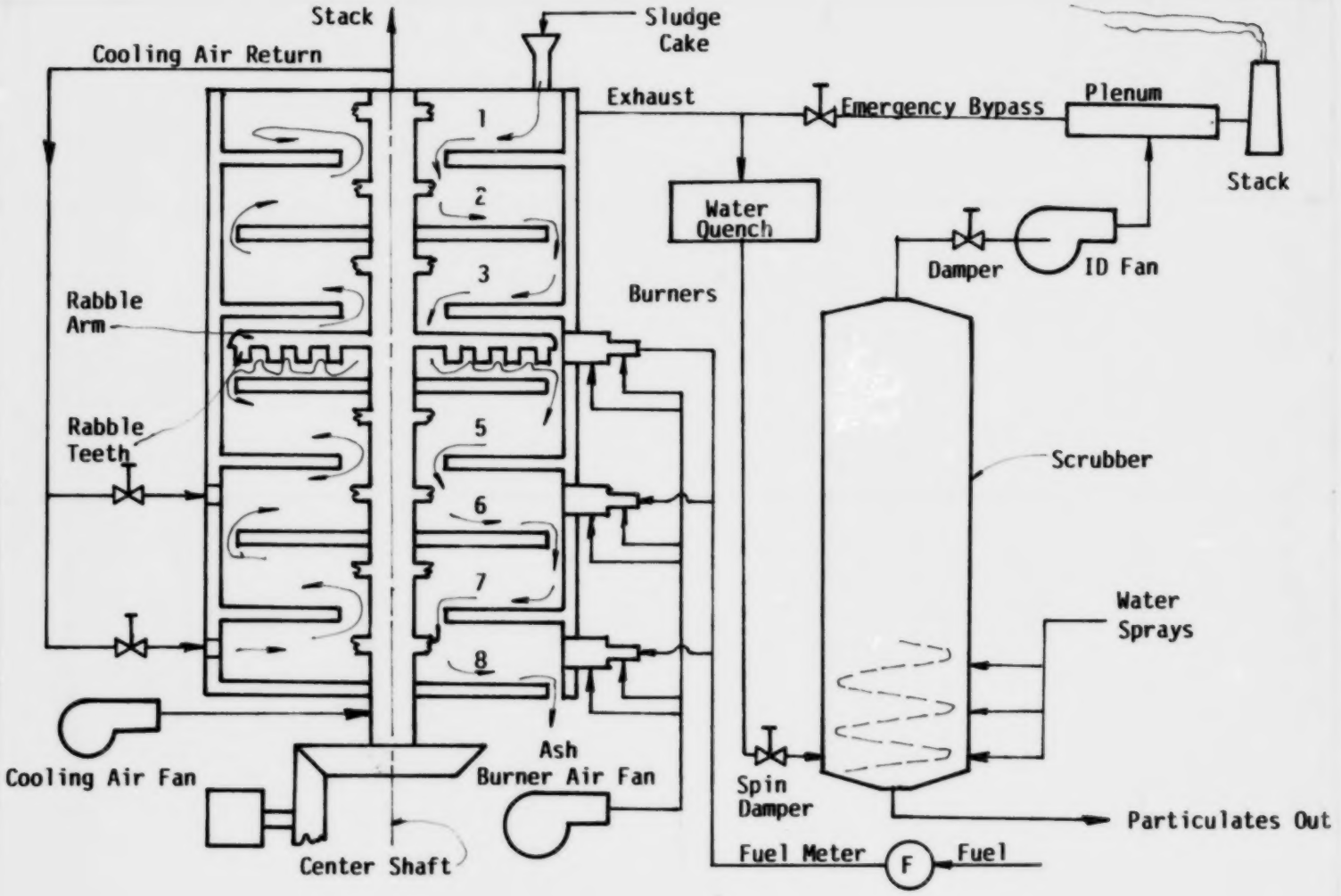

Figure 2. Indianapolis Incinerator System Schematic

tion gases and then burns on the middle hearths. The hot ash cools and is discharged from the bottom of the incinerator. The central shaft and rabble arms are air-cooled with the heated cooling air emerging from the incinerator at 150°C (300°F). The heated cooling air can be discharged to the atmosphere, or be returned to the incinerator at the 6 and/or 8 hearth levels.

The incinerator has nine fuel oil burners located in banks of three on hearths 4, 6 and 8. Atomization and combustion air are supplied to the burners, and burner fuel flow was varied by changing combustion air pressure by means of manual valves. A "Ratiotrol" valve proportions fuel pressure to combustion air pressure to maintain constant burner fuel/air ratio over the burner firing range. Additional fuel flow control was exerted by a variable area "Sensitrol" fuel valve. Additional air could be drafted in at each burner through adjustable air registers. The burner operation was completely manual and could be individually scheduled over a wide fuel flow range.

Additional air could be admitted into the incinerator through adjustable peep holes and doors, two of which are fitted at opposite sides on each hearth level. The Indianapolis incinerators had no exhaust gas analyzers to aid in setting incinerator air flow. This is a common situation because exhaust gas analyzers frequently prove unsatisfactory due to sample line plugging with incinerator particulates. Consequently, they are not installed, or, if installed are frequently not operable.

The incinerator exhaust is water-quenched, scrubbed, and exhausted to the stack plenum by means of an induced-draft (ID) fan, as shown in Figure 2. The scrubber has twelve water spray nozzles in the bottom located on four levels to thoroughly wet the particulates. The particulates are then centrifuged to the wall by a swirl set up by tangential air entry through an adjustable "spin damper". The separated particles then wash down the scrubber walls for collection. The scrubber is a very simple, low-energy system (1 kPa, 4 inches of water) which has no internal trays.

The incinerator operation and control was completely manual. The Indianapolis incineration process indications were as follows:

- combined sludge cake feed rate to two incinerators
- sludge cake moisture and volatiles measured every few hours
- incinerator draft
- incinerator gas temperature on each hearth level (recorded on a temperature chart)
- totalized fuel flow (recorded every hour)

The conveyor weigh scales indicated combined feed to two incinerators, which are supplied by a common belt. The flow split between incinerators is adjusted manually and visually estimated.

SECTION 5

TECHNICAL ASSESSMENT

POTENTIAL FUEL REDUCTION

The Plant-Scale Demonstration of Sludge Incinerator Fuel Reduction project was undertaken in Indianapolis based on the excellent fuel reduction potential for this incinerator operation. The fuel reduction potential of this incinerator plant was established analytically and confirmed by trial runs on one incinerator.

Analytical Assessment

An incinerator fuel prediction analytical model was employed to predict the lowest possible, or potential, fuel consumption obtainable by optimum incinerator operation. Variables considered in the analytical model are illustrated in Figure 3. This model predicts incinerator fuel requirements on the basis of completing all incineration processes including sludge cake drying, combustion, and ash cool-down in the available incinerator volume. The model is kinetic and it calculates, integrates, and iterates on gas temperatures, composition, and heat transfer rates which vary throughout the incinerator to arrive at a process-rate-determined solution. Energy balances are accomplished as only a first step in the solution. The analytical model employed is a distinct improvement over previous analyses which accomplished only an overall energy balance.

The predicted minimum fuel consumption for the Indianapolis incinerators is shown in the analysis print-out in Table 2. The analysis was made for the following typical Indianapolis conditions:

- 6.78 m (22.3 feet) diameter incinerators
- 8 hearths
- 6.4 metric ton/hr (7 tons/hr) wet sludge cake feed rate
- 65% cake moisture
- 30% cake moisture

Pilot Test

The Indianapolis incinerator fuel reduction potential was confirmed by a pilot test prior to the initiation of this demonstration program. A three and one-half day pilot test was accomplished on one of the incinerators (Ref. 1 and 2). The test incinerator was standard equipment except for the

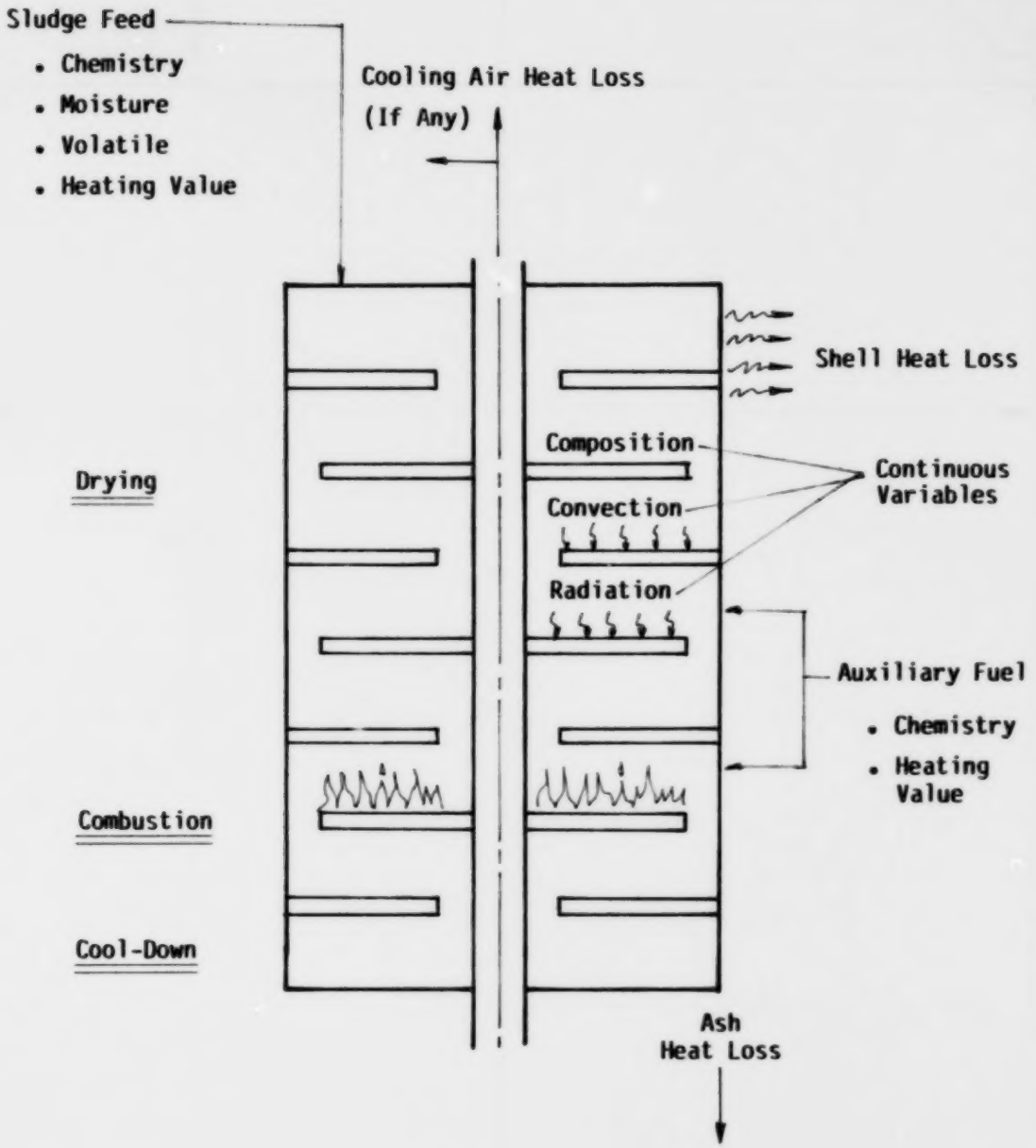

Figure 3. Incinerator Analytical Model

TABLE 2. INDIANAPOLIS INCINERATOR ANALYSIS

Incinerator Geometry

Shell Outer Dia	(M)	= 6.78
	(FT)	= 22.2
Shell Inner Dia	(M)	= 6.10
	(FT)	= 20.0
Height	(M)	= 10.3
	(FT)	= 33.7
No. of Hearths		= 8
Comb + Cooling		= 3
Hearth Thick	(M)	= 0.28
	(FT)	= 0.75
Hearth Air Gap	(M)	= 0.66
	(FT)	= 2.46

Feed Input Conditions

Feed (Wet KG/H)	= 6350
(Wet TONS/HR)	= 7
Moisture (%)	= 65
Volatile (%)	= 30
Vol HHV (KJ/KG)	= 39100
(BTU/LB)	= 10000
Hydrogen Coeff	= 1.61
Oxygen Coeff	= 0.46
Nitrogen Coeff	= 0.05

Fuel and Operation

Fuel HHF (KJ/M3)		= $37,643 \times 10^3$
Fuel H2 Coeff		= 1.95
Excess Air (%)		= 50
Ambient Temp	(C)	= 25
	(F)	= 77
Ash Temp	(C)	= 360
	(F)	= 680
Wall Temp	(C)	= 66
	(F)	= 150

Analytical Solution

Energy Source	KJ/H	BTU/HR	%	H#	T(C)	T(F)	KG/H	LB/HR	CUM %
Sludge Volatiles	1.55 E+7	1.47 E+7	76	1	427	802	332.8	733.8	8.1
Auxiliary Fuel	0.48 E+7	0.46 E+7	24	2	482	899	425.2	937.7	18.4
				3	554	1030	604.1	1332.2	33.0
				4	648	1235	948.4	2091.2	56.0
Sludge Water	1.33 E+7	1.26 E+7	65.5	5	877	1611	1815.3	4002.9	100.0
Comb Products	4.79 E+7	4.45 E+7	23.1						
Excess Air	1.36 E+7	1.29 E+7	6.7						
Ash	4.36 E+7	4.14 E+7	2.2						
Shell Loss	4.78 E+7	4.54 E+7	2.4						

Fuel Consumption Summary

Required Fuel Flow:
(Liters/Hr) = 117
(Gallons/Hr) = 31

Specific Consumption:
(Liters/Wet KG) = .0184
(Gallons/Wet Ton) = 4.44

installation of a fuel flow rate meter to aid in operational control. Oxygen analysis was not employed. Specific settings employed during this pilot test were previously developed (Ref. 1) from development tests which did accomplish incinerator exhaust gas analysis to optimize excess air. Fuel consumption results obtained during the pilot test are shown in Figure 4. Fuel consumption was reduced from a 1977 baseline value of 37 liters per wet metric ton (8.9 gal per wet ton) to 18 liters per wet metric ton (4.4 gal per wet ton), a 51% reduction. These improvements were achieved at a load rate 10% greater than the baseline operational average. As anticipated from the analytical studies, the pilot test specific fuel consumption was essentially constant over the large load variation encountered during the test. This was in sharp contrast with the 1977 baseline fuel consumption which had a large fuel consumption increase with load decrease, as shown in Figure 4.

Another significant aspect of the pilot test was the very steady operation achieved. A typical temperature record is shown in Figure 5. Temperatures were virtually constant on all hearth levels, and maximum temperature was 900°C (1650°F). This was in sharp contrast with past operations which were often characterized by cyclic temperatures, and intermittent maximum temperatures of 1000°C (1800°F) and higher. Such cyclical and high temperature operation is very harmful to incinerator internal parts life.

The analysis and pilot test indicated that a 50% fuel reduction was physically possible for the Indianapolis incinerators. The full-scale incinerator fuel reduction project was initiated on this basis. The potential incinerator fuel reduction at any particular plant depends on local equipment and operational factors. Analysis of several other plants has indicated a fuel reduction potential from 0% in some plants to 100% in other plants.

IMPLEMENTATION REQUIREMENTS

Incinerator fuel reduction implementation requires improvements in routine incinerator operating procedures. In Indianapolis, for example, the following operational guidelines were developed (Ref. 1):

1. Maintain excess air at 25-50%
2. Utilize center shaft cooling air in the incinerator when possible
3. Maintain sludge combustion on hearth 6
4. Introduce auxiliary combustion on hearth 8
5. Maximize use of hearth 6 burners
6. Maintain sludge cake loading to design rate or less
7. Employ slowest possible center shaft speed
8. Minimize incinerator air leakage

Implementation of these previously developed guidelines to routine operation is complicated by changes in sludge feed rate, moisture content, volatile, and, at times, volatile heating value. These process changes are characteristic of incinerator operation.

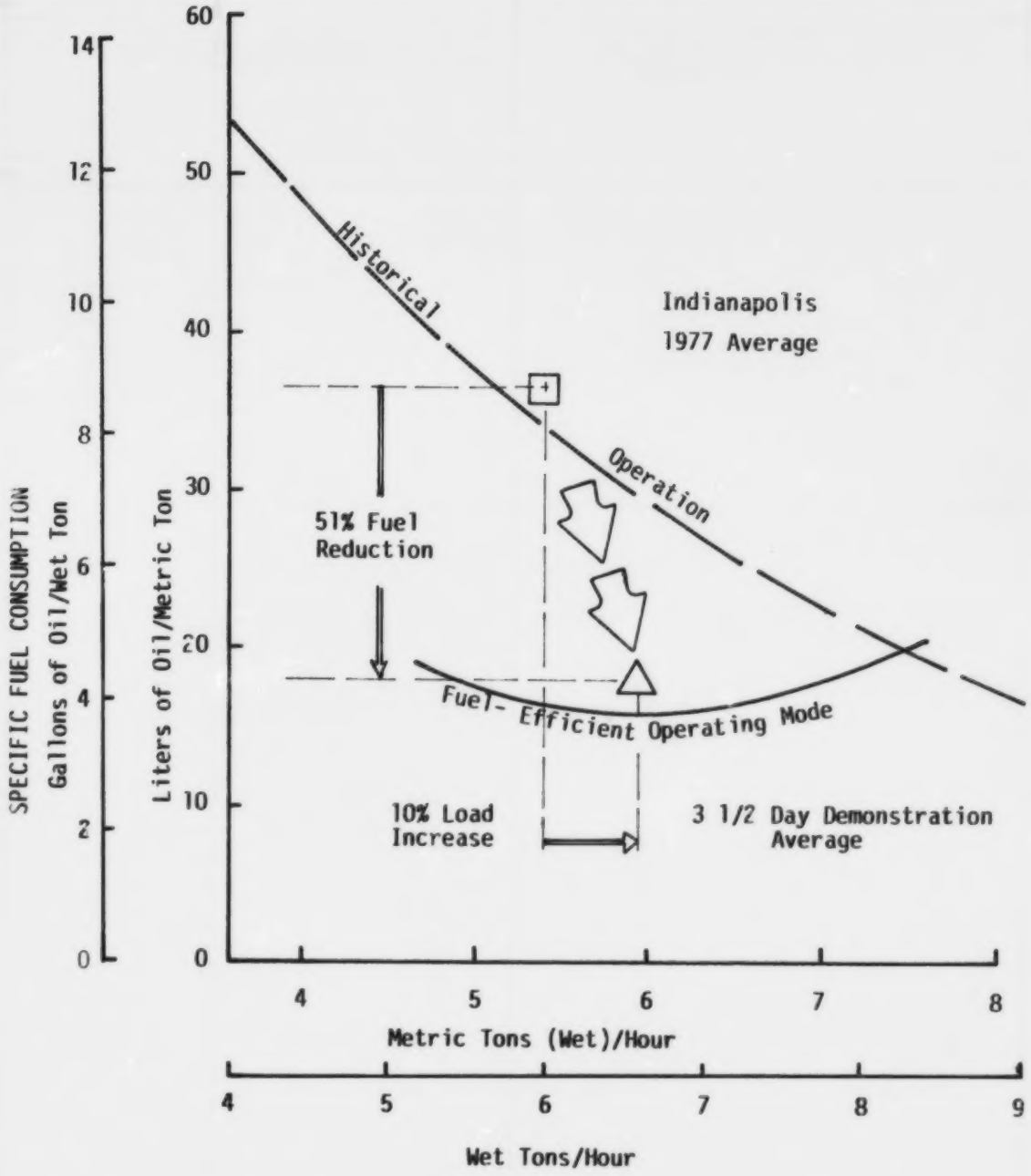

Figure 4. Pilot Test Results

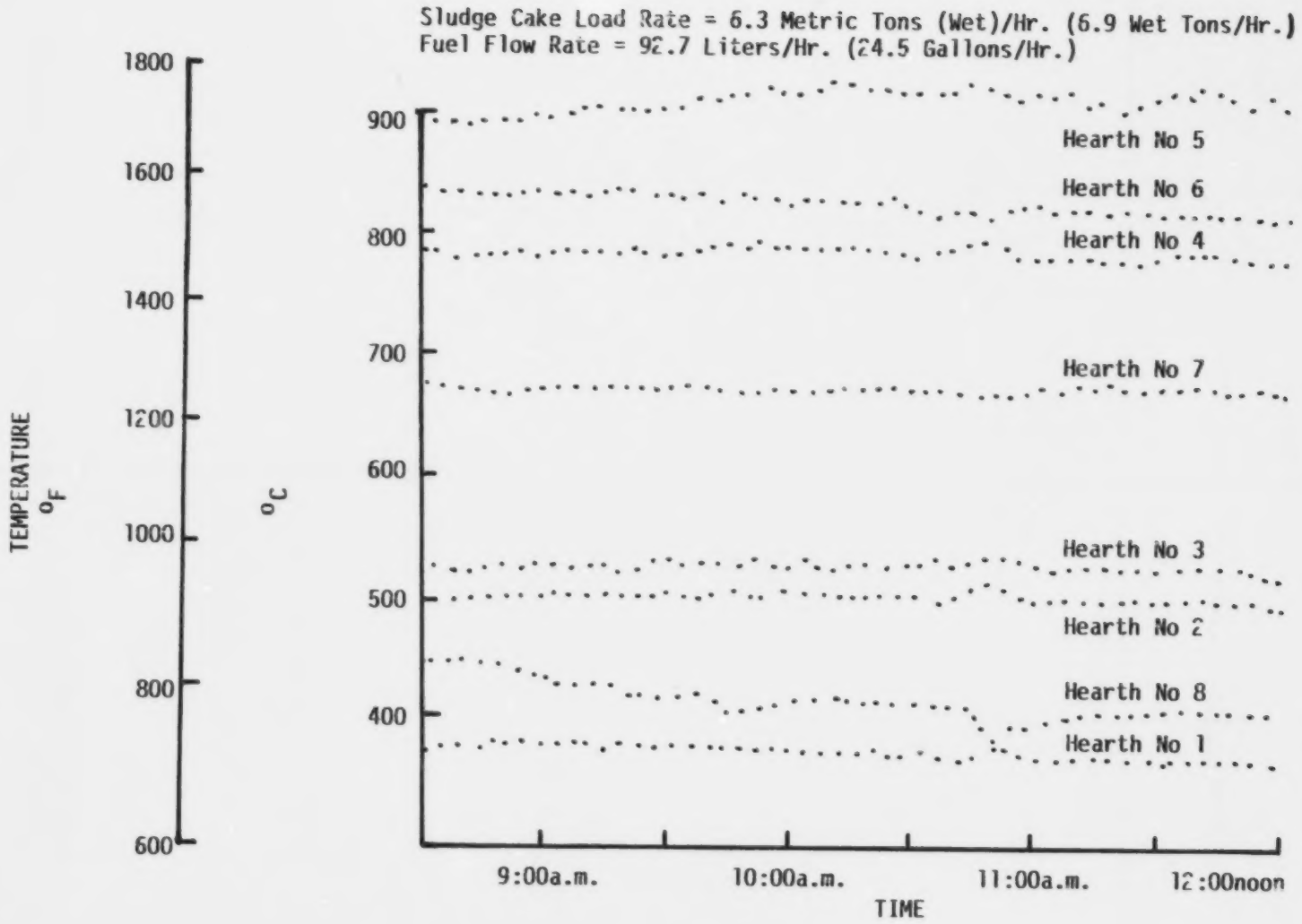

Figure 5. Pilot Test Temperature Stability

In order to maintain fuel-efficient operation in spite of these process changes, the following is required:

1. Adequate incinerator instruments and controls
2. Operator training to accomplish routine operations in a fuel-efficient mode

The Indianapolis incinerator instruments and controls, as described in Section 4, were inadequate to allow precise process control. Important information such as excess air, individual incinerator feed rate, and incinerator fuel flow rate was not available. None of the incinerator controls were remote. Thus, control changes could only be made at the physical control valve locations. The Indianapolis incinerator operation has one incinerator operator for four incinerators. With remote controls lacking, the operator work load was much too high to maintain accurate control and fuel consumption was much higher than necessary.

An assessment of the Indianapolis incinerator operation indicated that the following five instrumentation and control systems would provide the equipment required to operate the incinerators consistently in a fuel-efficient mode:

1. Sludge Flow Rate Measurement System
2. Oxygen Analysis System
3. Fuel Flow Rate Measurement System
4. Remote Fuel Control System
5. Remote Air Control System

The overall instrumentation and control improvement concept is illustrated in Figure 6. The control room improvements are illustrated in Figure 7. The rationale for these systems is briefly discussed in the following paragraphs.

Sludge Flow Rate Measurement System

Knowledge and control of the incinerator feed rate is of major importance. As previously discussed, the original weigh system only provided total feed information for two (or more) incinerators, necessitating individual feed rates to be visually estimated. This situation provided unsatisfactory control of this vital variable. The sludge feed split between incinerators can change at any time with slight variations in sludge location on the conveyor belt. Sludge feed rate was also not indicated in the filter room. As shown in Figure 6, the improved sludge measurement system employs two weigh scales to provide individual recorded feed rate information for each incinerator in the control room. Feed rate to the first incinerator is determined by difference. Another important improvement of the Sludge Flow Measurement System is a total feed rate recording in the filter room. This enables the filter operator to maintain a more steady feed rate.

Oxygen Analysis System

Excess air control is very important for fuel consumption reduction.

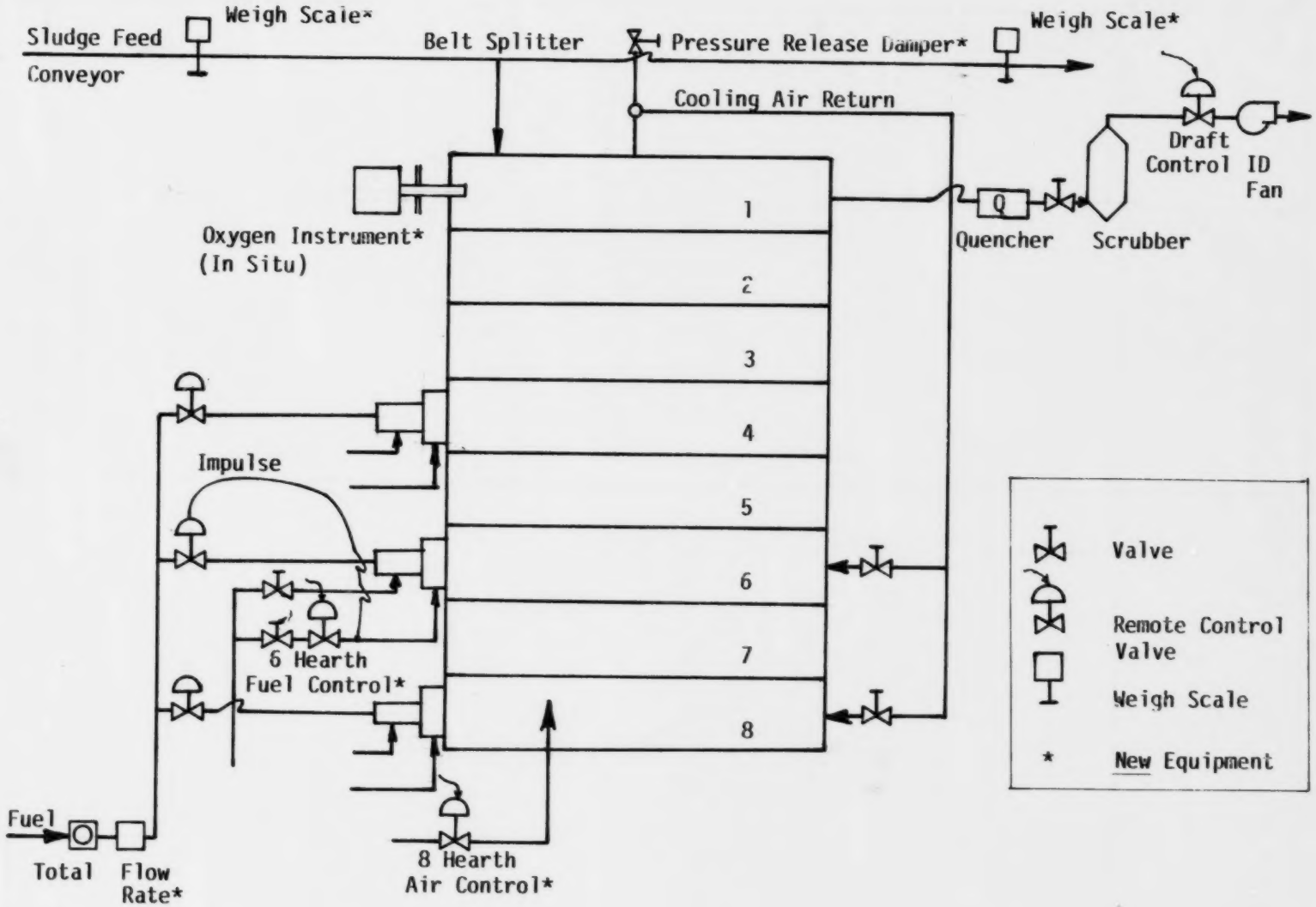

Figure 5. Instrumentation and Control Improvement Concept

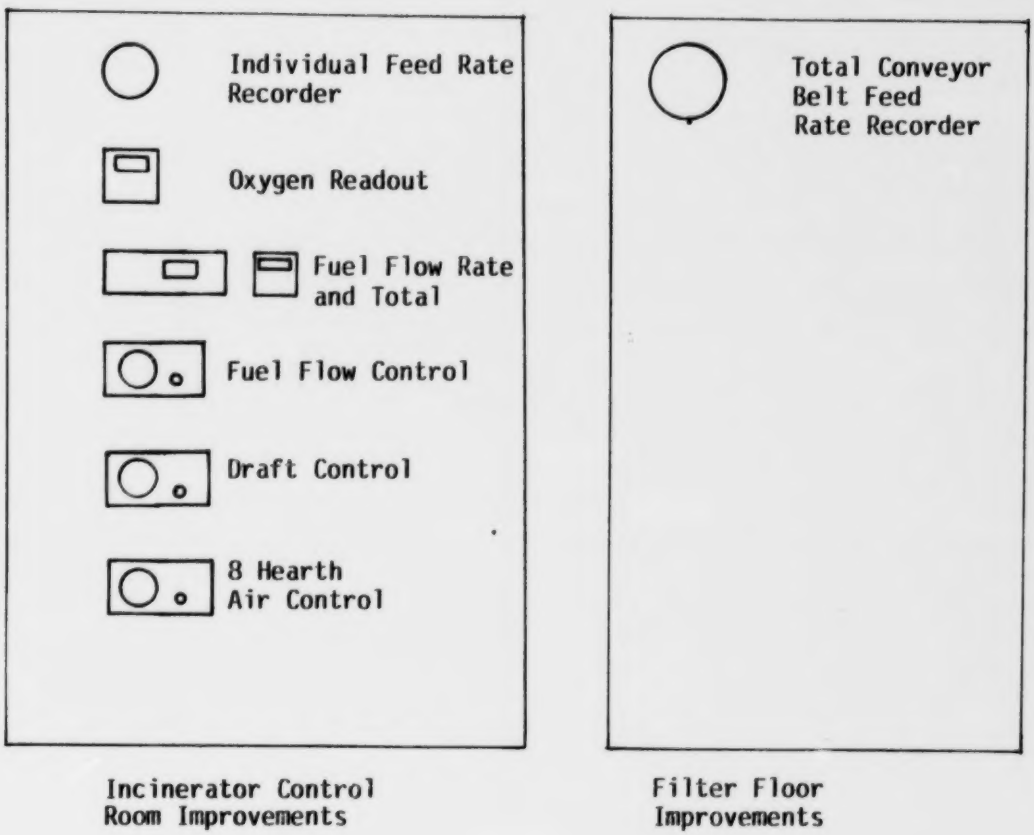

Figure 7. Control Room Panel Design Concept

Excessive air increases incinerator heat loss and consequently fuel consumption. Insufficient air causes smoke and combustion inefficiency with increased fuel consumption. Excess air is best determine routinely by exhaust oxygen analysis. As shown in Figures 6 and 7, the instrumentation-control system includes installation of oxygen analyzers on each incinerator at the first hearth level with readout in the control room.

Fuel Flow Rate Measurement System

The original system only had fuel totalizers. A fuel flow rate instrument provides important process control information. For any sludge feed rate and moisture and volatile content, there is a required fuel flow to provide stable operation. This fuel requirement can be predicted and provided as a guideline for incinerator operation. With experience, the operator may set the incinerator fuel flow rate and quickly achieve stable operation. This eliminates the large temperature cycles that characterized past operations. As shown in Figures 6 and 7, the fuel flow rate instrument is installed in the fuel feedline. The fuel flow rate and total fuel used are presented digitally in the control room.

Remote Fuel Control System

Fuel flow rate changes are routinely required to accommodate sludge feed rate changes. The original equipment required adjustment of individual burners. To reduce operator workload and allow more precise incinerator operation, remote-operated burner controls were installed on the 4 and 6 hearth burners as illustrated in Figures 6 and 7. The 8 hearth burners were not remote-controlled because these burners are rarely used.

Remote Air Control System

Incinerator airflow changes are routinely required to accommodate sludge feed changes and sludge burning level changes. For example, a rising sludge burning zone temporarily requires a large increase in incinerator combustion air to consume the additional sludge volatiles, whereas a descending sludge combustion zone temporarily requires a reduction in incinerator airflow.

Incinerator airflow depends on incinerator draft and incinerator open area. The original airflow controls were manual. The draft was controlled by a draft control damper between the scrubber and the ID fan. The incinerator open area was controlled by hearth and peep door open areas on each hearth level. As shown in Figures 6 and 7, the improved system controls the draft damper position and the incinerator open area on hearth No. 8 from the control room. The return cooling air was not remotely controlled because it was determined that under normal sludge feed rate conditions, that all the cooling air could be returned to the incinerator so that modulation of this air would not be normally required. The remote airflow controls also reduce operator work load, thereby making more precise incinerator operation possible.

The equipment installation details are discussed in Section 6. Operator training is discussed in Section 7. Fuel consumption results are presented in Section 8. The impact of the improved operation to particulate emissions is discussed in Section 9.

SECTION 6

EQUIPMENT INSTALLATION

SLUDGE FLOW MEASUREMENT SYSTEM

North Incinerator Building

The North Incinerator Building sludge feed system and improved sludge flow measurement system are shown schematically in Figure 8. East and West conveyor belts feed sludge cake to two in-line incinerators each. The sludge split on each belt is set manually by a splitter blade. New weigh scales "A" and "B" were installed upstream and between the incinerators, respectively, in order to establish loads to the individual incinerators. The upstream incinerator feed rate is determined by the difference: $W_2 = W_A - W_B$.

The control room instrumentation is shown schematically in Figure 9. The individual weigh scale speed and weight information is transmitted to a weight processor mounted in the incinerator control room. The weight processor digitally displays the total belt feed rate and the belt totalized weight. The weight processor also supplies signals to drive the individual feed rate recorders for each incinerator. The total belt feed rate is also recorded and displayed in the filter room. The major sludge flow measurement system components including the scales and weight processors are identified in Appendix A.

South Incinerator Building

The South Incinerator Building incinerator/conveyor system is shown schematically in Figure 10. Two inclined conveyor belts deliver the sludge cake to an elevated cross-flow conveyor belt which supplies the four in-line incinerators. The layout of the South Building conveyor system would have required five individual weigh scales to determine specific incinerator feed rates. The installation of the scales would have also required extensive changes in idler and incinerator drop chute locations. These and other problems with the current conveyor system layout made it necessary to postpone the installation of a new weigh scale system in the South Building until after the conveyor system is changed sometime in the future. The recommended conveyor/weigh scale system is shown in Figure 11.

FUEL FLOW RATE MEASUREMENT SYSTEM

North Incinerator Building Installation

The fuel flow rate measurement system is shown schematically in Figure

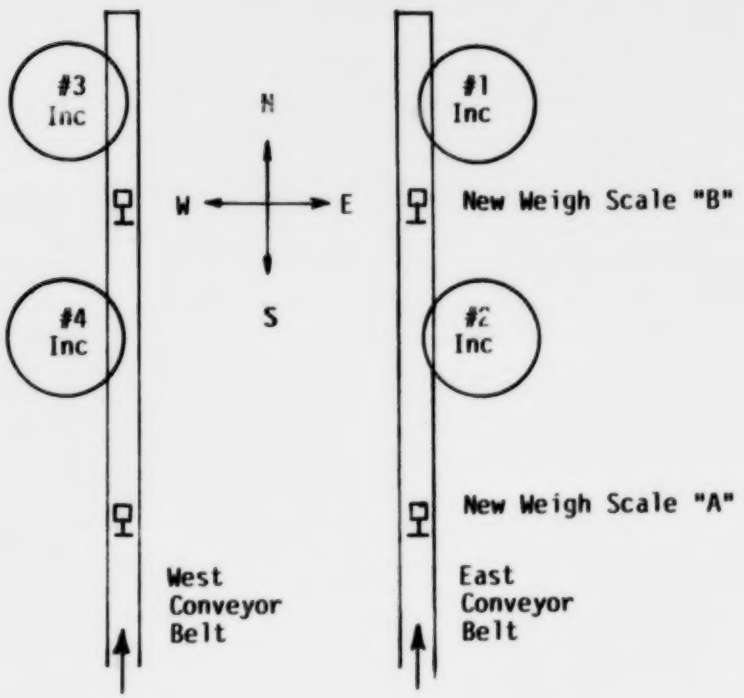

Figure 8. North Incinerator Building New Weigh Scale Installation

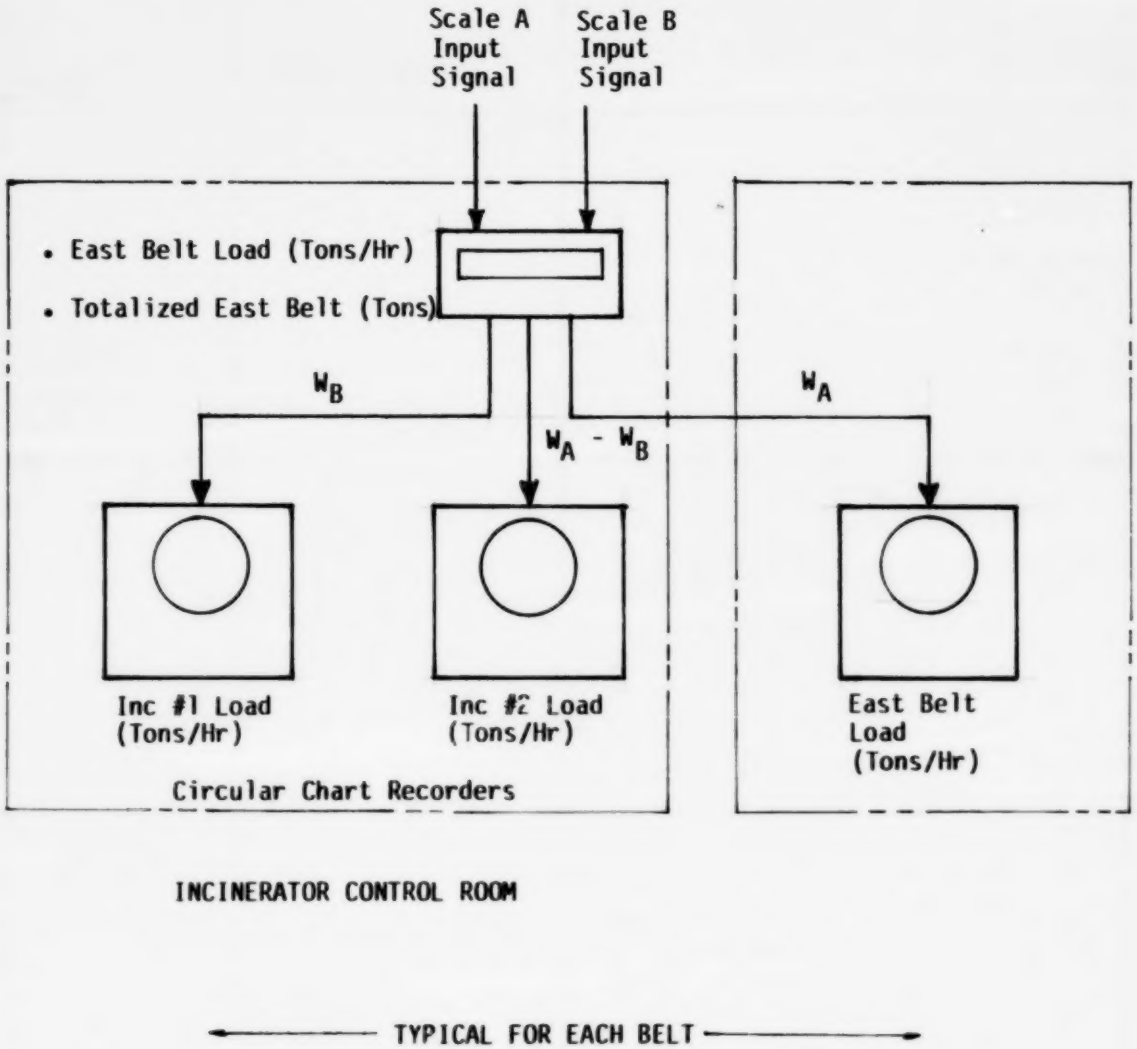

Figure 9. North Incinerator Building Weigh Scale Control Room Instruments

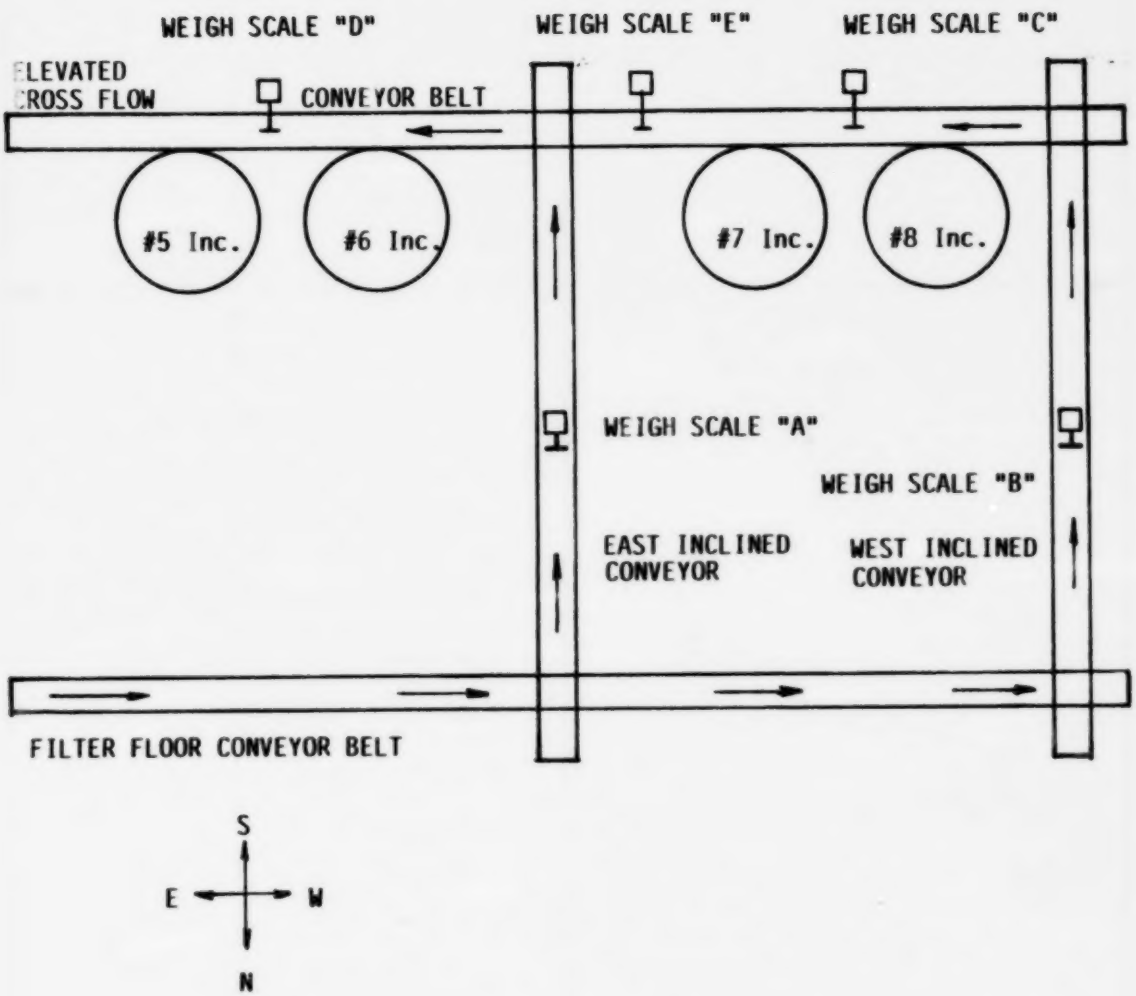

Figure 10. South Incinerator Building Weigh Scale System for Existing Conveyor System

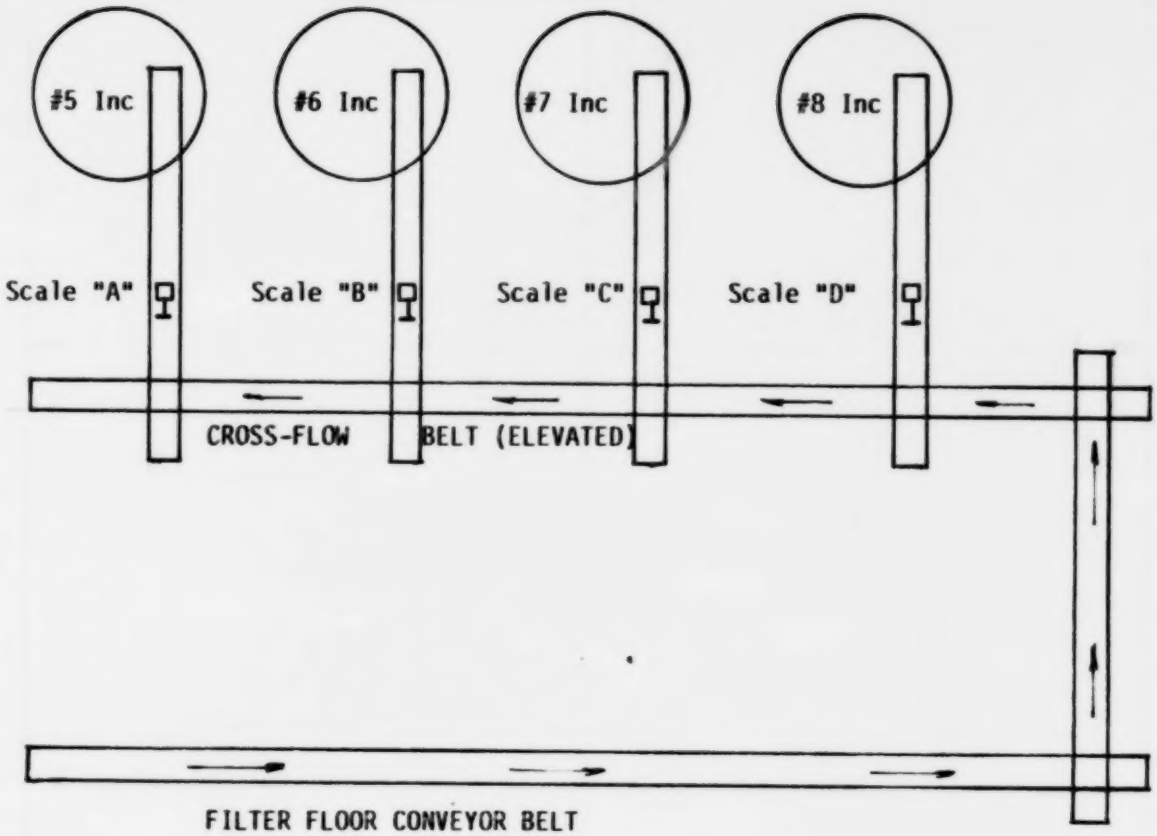

Figure 11. Recommended South Incinerator Building Conveyor System and Weigh Scales.

12. A fuel flow rate meter and filter are installed in-line with the current fuel flow totalizer. A bypass loop is provided for this system to allow service without incinerator shutdown. The fuel flow rate meter has a 4-20 ma signal which drives a control room fuel flow rate digital read-out and fuel totalizer. One fuel flow rate system is installed on each incinerator. A true mass-flow rate measuring system was selected. This measures true mass flow, independent of liquid fuel properties such as density and viscosity. This versatility is important because Indianapolis uses No. 2 fuel oil as well as blends of reprocessed waste oil. A "FLOTRON" fuel flow rate meter that uses a hydraulic wheatstone bridge principle for flow measurement was selected. The flow rate meter was specified for 0-454 kg/hr (0-1000 lb/hr). The selected equipment is specified in Appendix A.

South Incinerator Building Installation

The South Incinerator Building originally had a common fuel feed line and Buffalo fuel totalizer for each two incinerators. Individual fuel feed lines were installed to supply the individual incinerators. Individual Buffalo meters and fuel shutoffs were installed similar to the North incinerator building. The fuel flow rate instruments for each incinerator were installed on a separate "flow bench". Equipment was the same as used for the North Incinerator Building.

General Experience

The installed fuel flow rate equipment was found to be suitable for the application with its rugged design and easy service features. The main problems encountered were frequent plugging of the 25 micron filter. This problem was aggravated by the use in Indianapolis of a blend of No. 2 heating oil and reprocessed waste oil. The reprocessed waste oil also caused problems with excessive burner plugging and coking. Because of these maintenance problems, Indianapolis is terminating the use of reprocessed oil until performance specifications for recycled oil can be implemented. The filter plugging problem was solved by using a larger 60 micron filter which has given excellent service in other applications. This filter size provides sufficient protection of the flow rate meter, while greatly reducing filter replacement frequency.

OXYGEN ANALYSIS SYSTEM

Concept Selection

Incinerator oxygen analysis systems have often been plagued by poor durability and high maintenance costs. These problems have generally resulted from plugging of the gas sampling system by incinerator particulates. Another problem experienced with incinerator oxygen analysis systems is imprecise excess air indication due to probe location far downstream in the exhaust system where large amounts of leakage air are present.

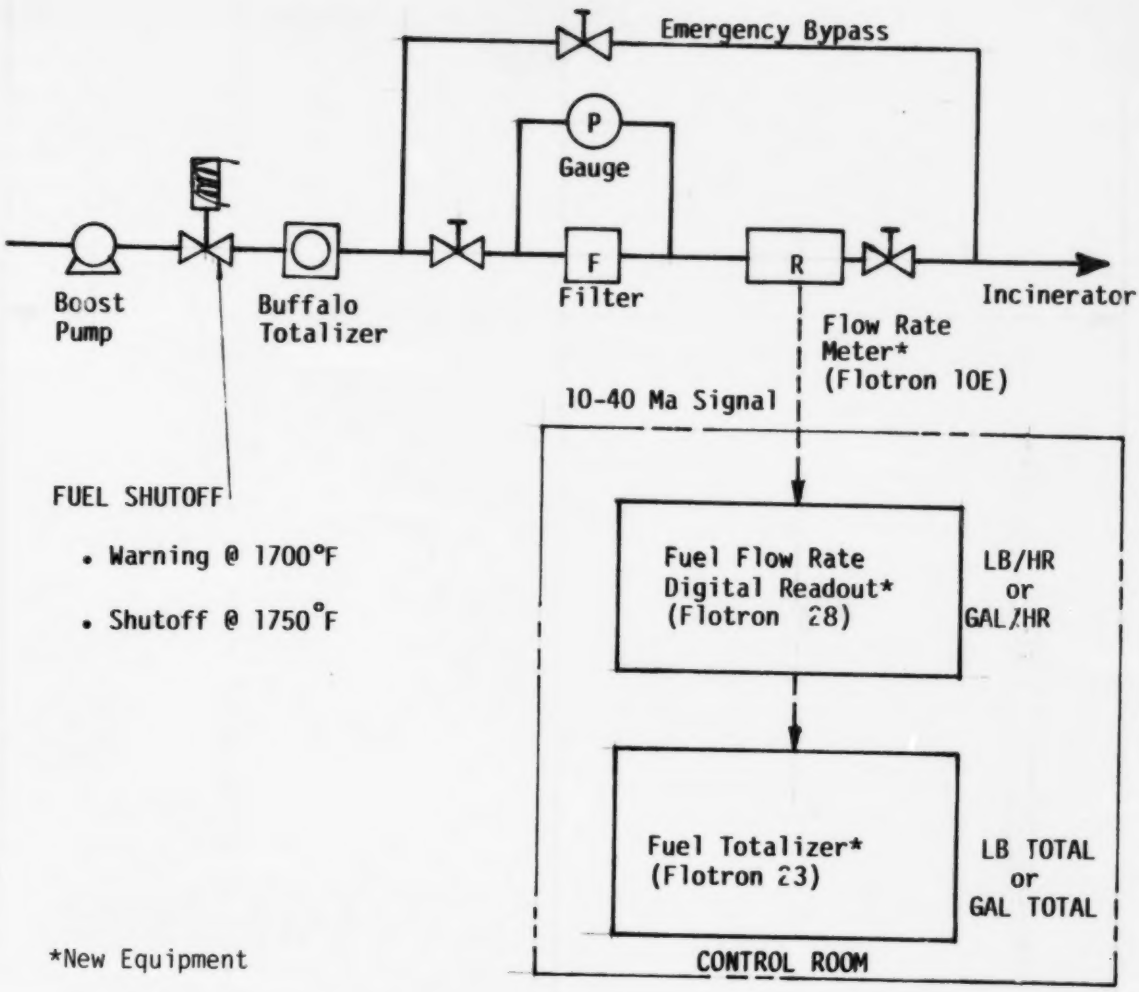

Figure 12. Fuel Flowrate Measurement System

These problems can now be overcome by in-situ oxygen analyzers. These analyzers avoid the plugging problem by eliminating gas sampling. The oxygen sensor is located directly in the process gas. A zirconium oxide cell is generally employed. This operates at high temperature to enable the analyzer to be located in high temperature zones of the incinerator thereby overcoming the air dilution problem.

The in-situ incinerator oxygen analysis system is shown schematically in Figure 13. A zirconium oxide oxygen probe is located inside the incinerator. The temperature of this cell is maintained at a constant temperature by a controller. Air is constantly supplied to one side of the cell to provide an oxygen reference concentration. Output from the cell is linearized and read out in a control room electronic unit (oxygen readout). A calibration gas system was designed to serve all four analyzers in each building for periodic calibration. Reference and calibration gas flows are very low (1 l/min), as measured by a panel-mounted rotameter.

The Hays "Oxyprobe" system was selected for use. A key feature of this system is the integrity of the zirconium oxide cell. In this system, the cell is surrounded by an oversized ceramic "filter" element. The filter element has no special tendency to plug because there is no net sample inflow; sample flow is by diffusion only. However, the ceramic filter is replaceable.

The major components of the oxygen analysis system are identified in Appendix A. The oxygen analyzer shown was installed in the No. 1 hearth airspace, as shown in Figure 14. Installation was very straightforward, involving welding a pipe section and flange to the incinerator shell. The oxygen analyzer circumferential location is shown in Figure 15. The analyzer was installed opposite the drop chute to avoid the dilution from air leakage into the drop chute.

Any in-situ oxygen analyzer measures the mole fraction of oxygen on a "wet" basis; i.e., with combustion water and sludge cake water vapor present. The excess air must therefore be established from the amounts of sludge cake water and combustion water in the exhaust gas. Excess air maps were generated based on the following chemistry:

- Fuel Oil = $CH_{1.95}$
- Sludge Volatile = $CH_{1.61}O_{.46}N_{.05}$.

The resulting relation between wet basis oxygen and excess air percentage is shown in Figure 16. The R parameter is the ratio of the sludge cake water to the total volatile, including the auxiliary fuel. "R" is a function of cake moisture, volatile content, and auxiliary fuel consumption. R maps for fuel consumptions of 12, 21, 29, and 37 liters per wet metric ton (3, 5, 7, and 9 gallons per wet ton) are shown in Figures 17 through 20. For practical purposes, R is generally in the range of 4 to 5. Thus, it may be seen from Figure 16 that an excess air value of 50% is indicated by a wet-basis oxygen reading of only 4.5%.

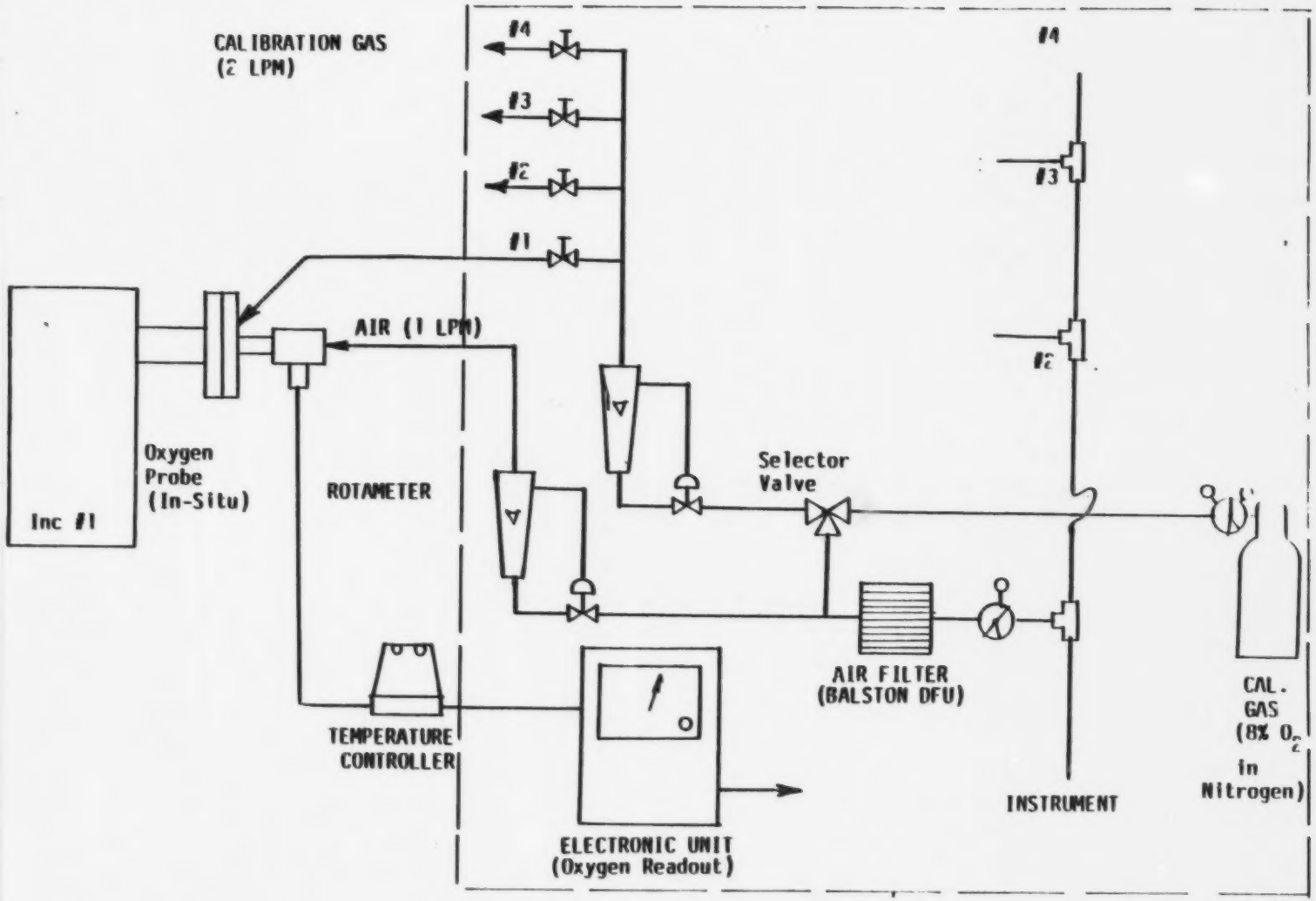

Figure 13. Incinerator Oxygen Analysis System

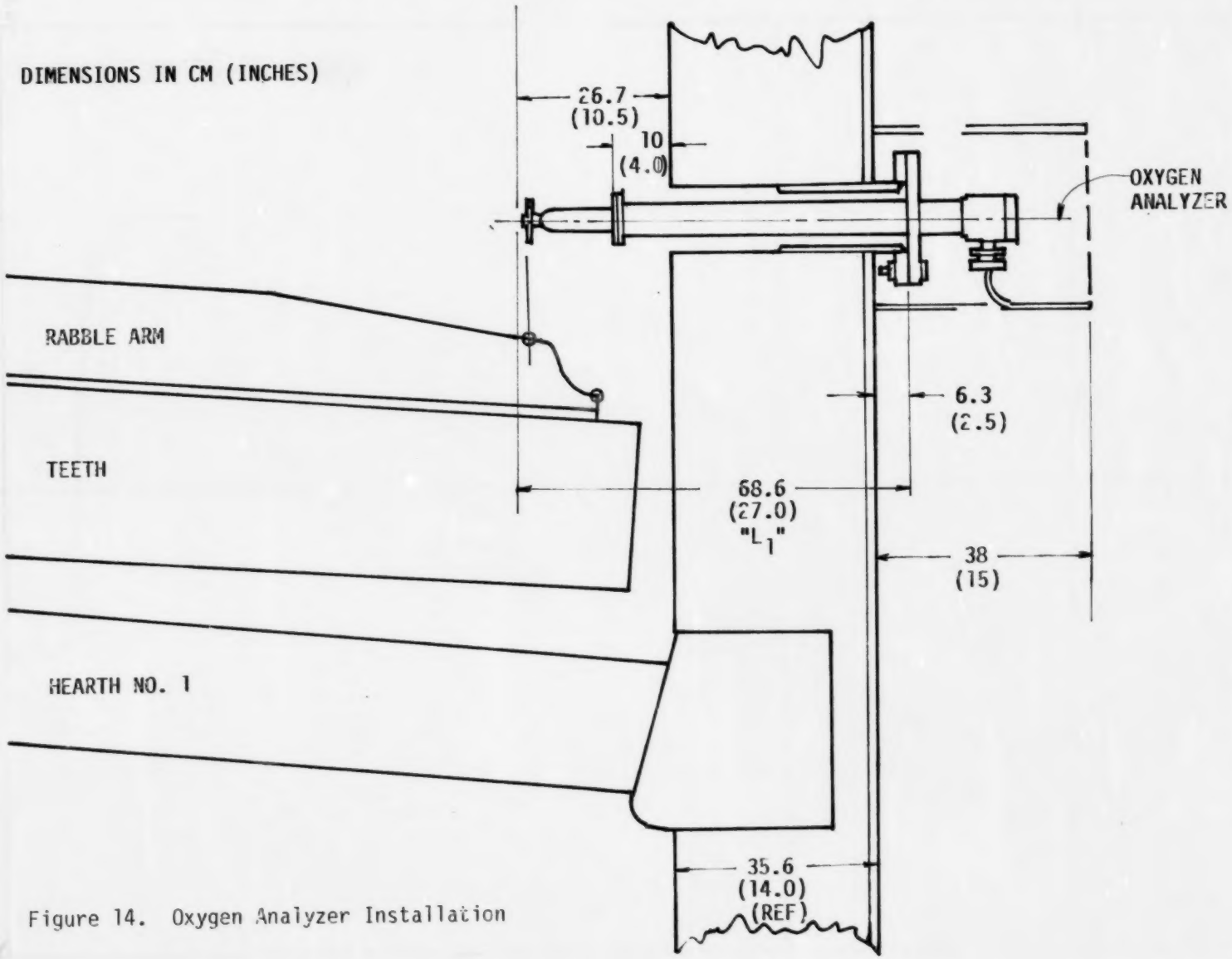

Figure 14. Oxygen Analyzer Installation

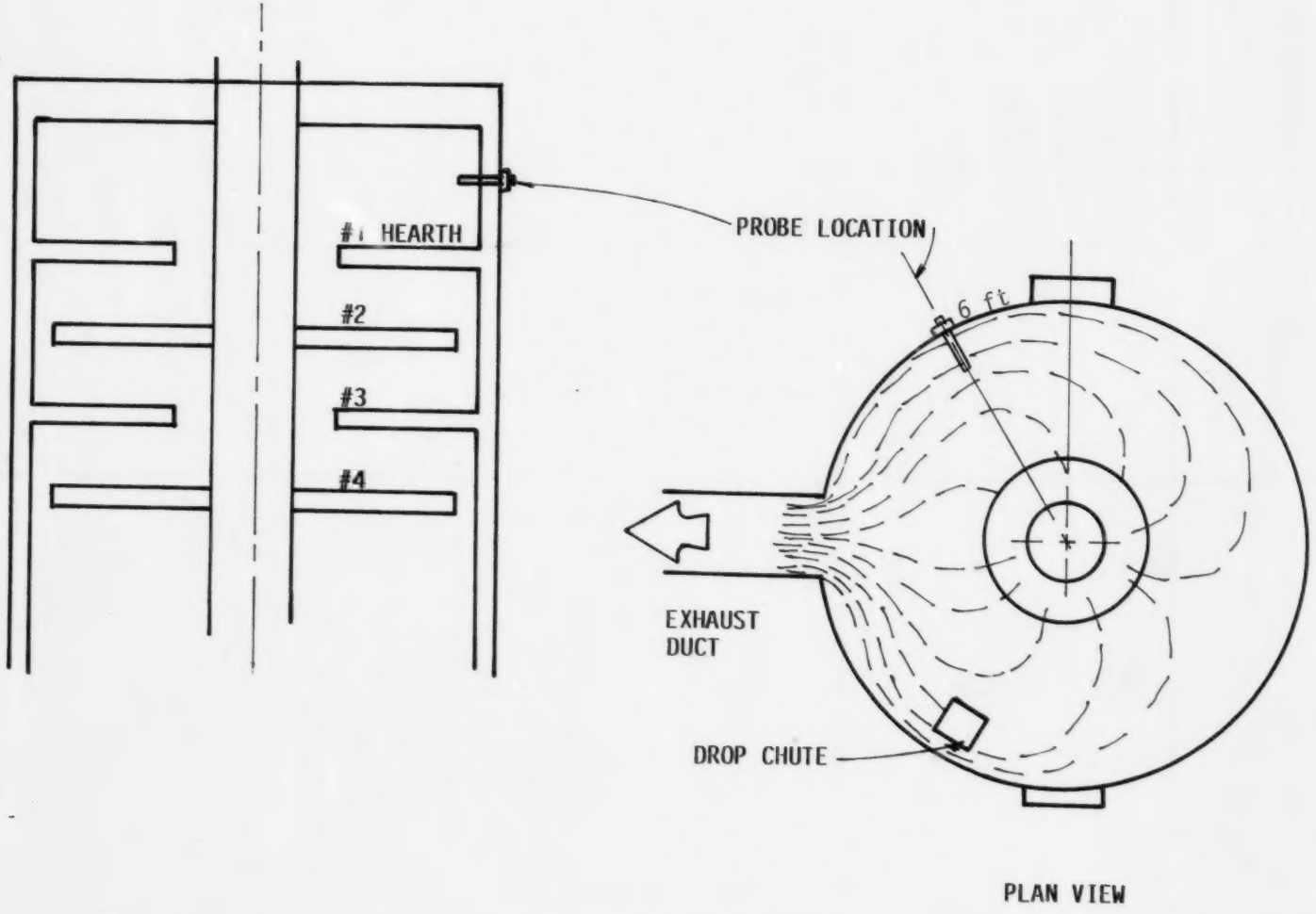

Figure 15. Oxygen Analyzer Circumferential Location

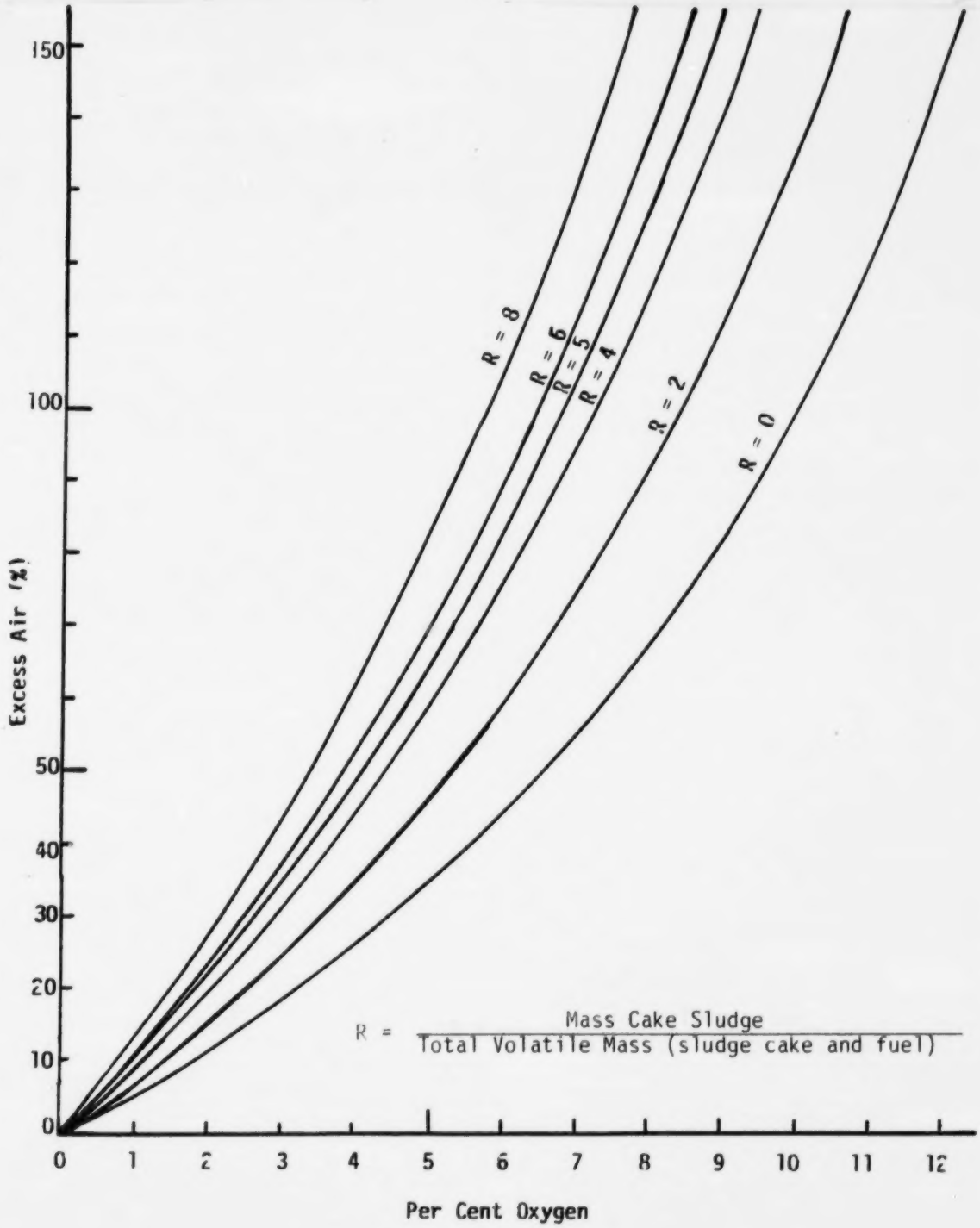

Figure 16. Incinerator Excess Air From Wet Basis Oxygen

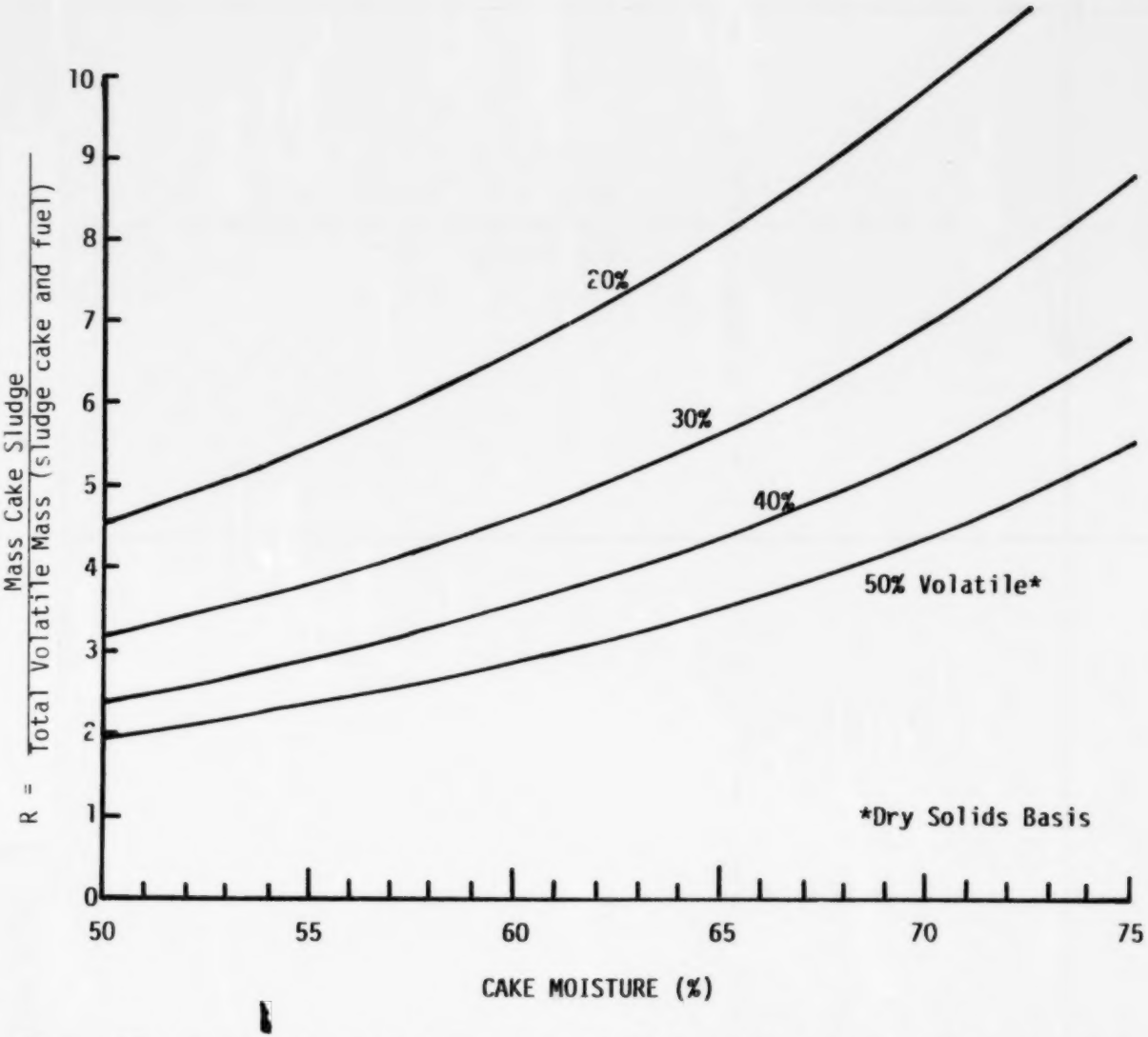

Figure 17. R Chart for Fuel Consumption of 12 Liters/Wet Metric Ton (3 gal/Wet Ton)

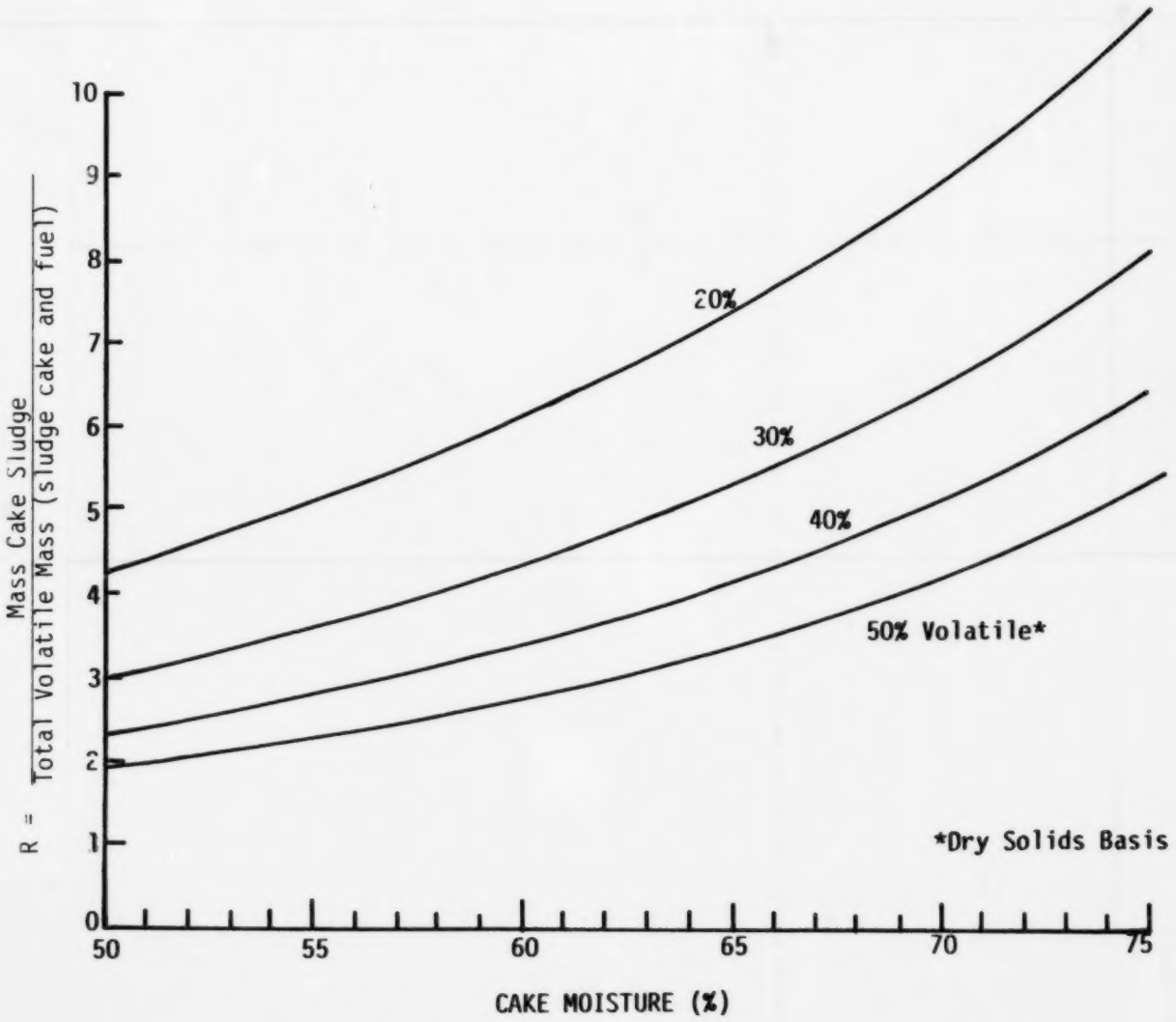

Figure 18. R Chart for Fuel Consumption of 21 Liters per Wet Metric Ton (5 Gal/Wet Ton)

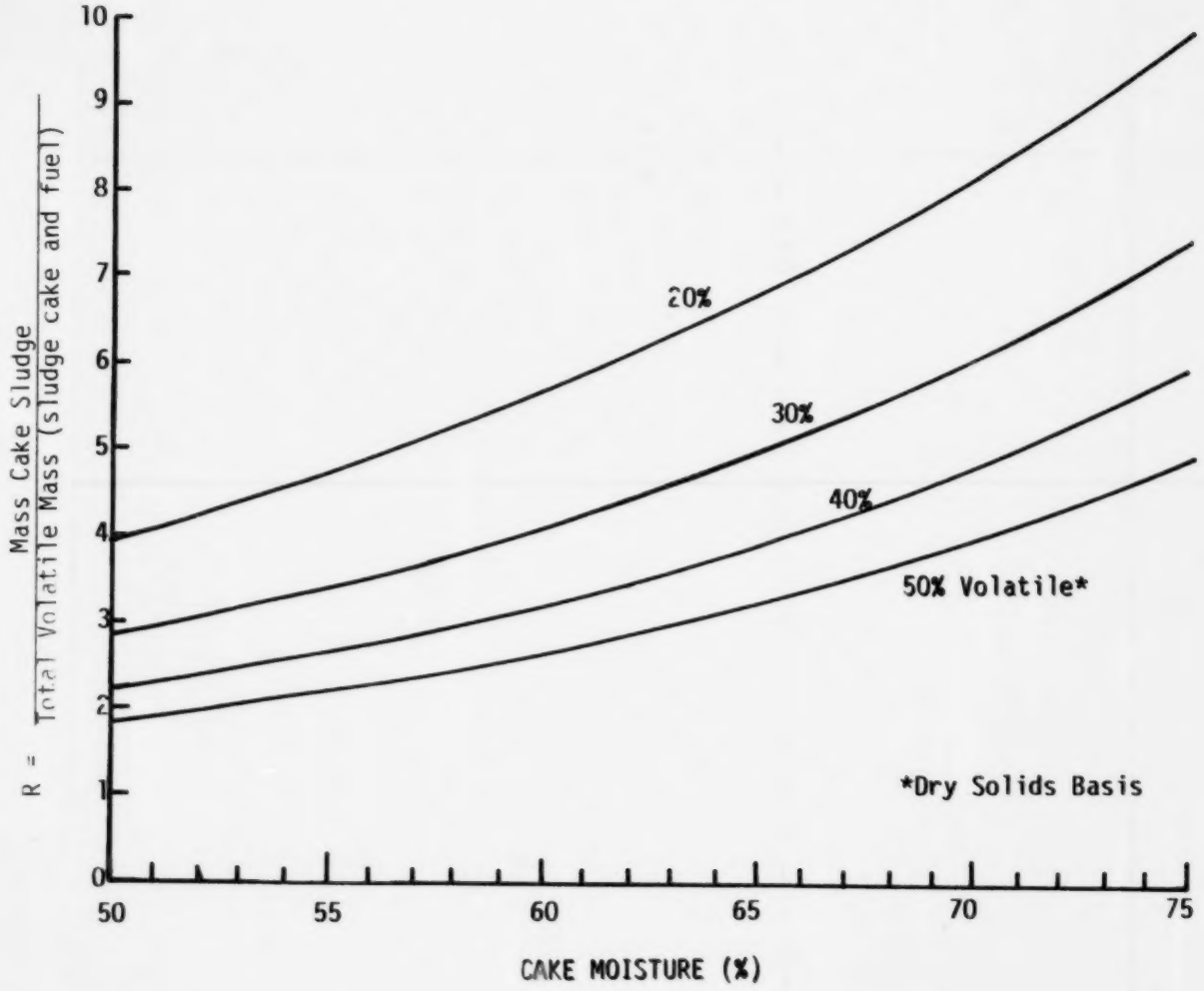

Figure 19. R Chart for Fuel Consumption of 29 Liters per Wet Metric Ton (7 Gal/Wet Ton)

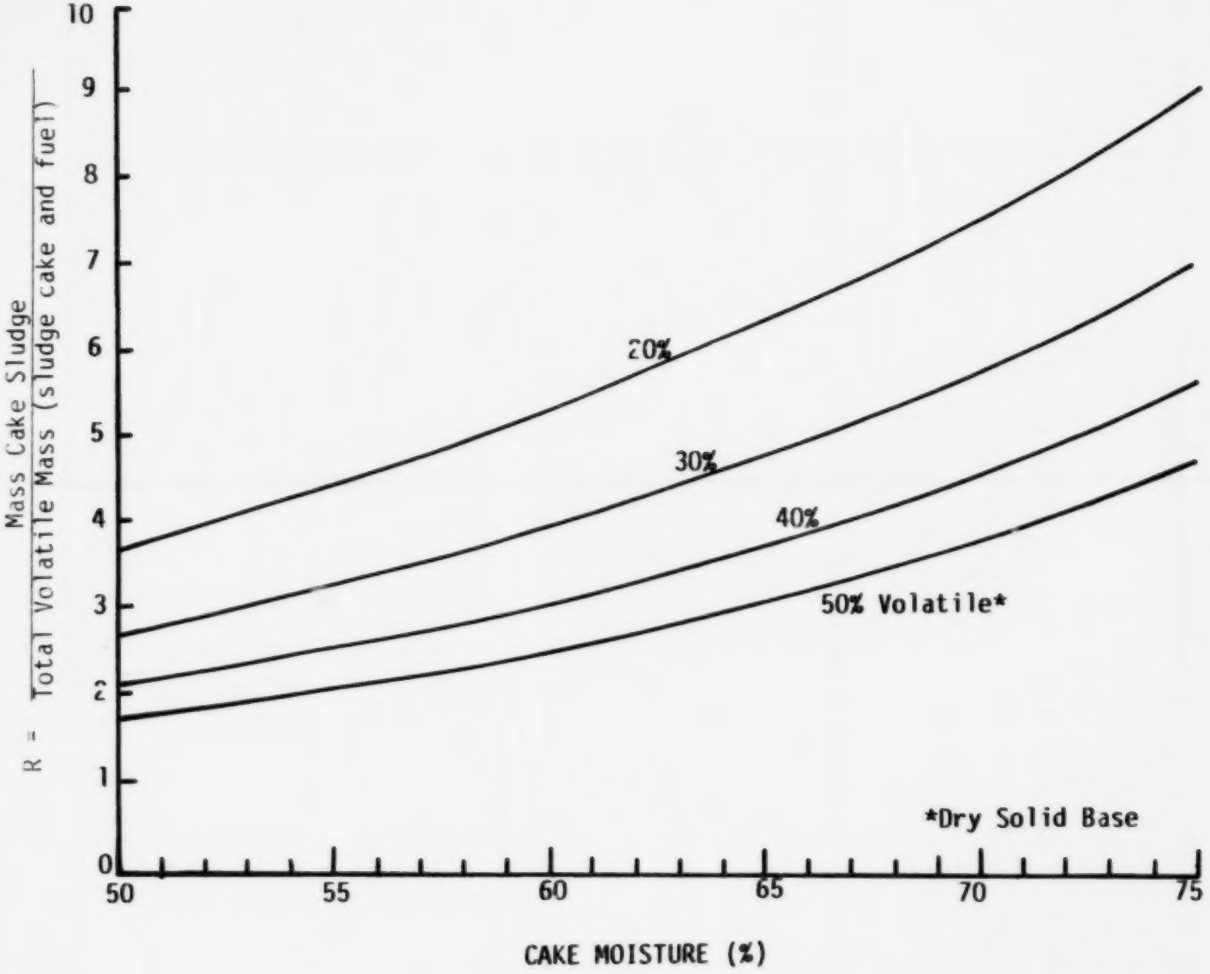

Figure 20. R Chart for Fuel Consumption of 37 Liters Per Wet Metric Ton (9 Gal/Wet Ton)

General Experience

The oxygen analysis system as designed and installed appeared very satisfactory. It proved necessary to lock the oxygen readout unit in the control room to prevent inadvertent calibration changes. Probe plugging was not encountered since installation (one year to date). The units provide realistic information that has become indispensable, especially for meeting air pollution standards. A recommended addition to the described basic system is a strip chart recorder. This would provide a continuous operational record for air pollution, supervisory purposes and process control. Together with other information, recorded oxygen would display operational trends such as a climbing fire.

FUEL FLOW CONTROL SYSTEM

Concept Selection

The remote-operated fuel flow control system is shown schematically in Figure 21. Pneumatic controls were selected to provide economical and rugged control in the severe operating environment. Instrument air at 690 kPa (100 psi) was reduced to 140 kPa (20 psi) by a pressure regulator. Control of fuel rate was manual; a control room manual load station provides the actual control signal 21-103 kPa (3-15 psi). The pneumatic signal moves diaphragm- actuated butterfly valves in each burner combustion air line. The burner combustion air pressure actuates the existing burner Ratiotrol controls which then vary burner fuel pressure and burner combustion air pressure thereby maintaining constant burner fuel/air ratio over the firing range.

Remote fuel controls were installed on the three 6 hearth burners and the three 4 hearth burners as shown in Figure 21; each burner control actuates all three burners on a hearth. The 8 hearth burners were not controlled because these burners are not used during routine operation. The diaphragm valves were set up to be fail-safe. Zero control in pressure resulted in an open valve so that manual firing rate control could be used in case of pneumatic system failure.

In order to provide a feedback indication of diaphragm valve motion, the combustion air pressure of each burner was displayed in the control room. In this manner unequal valve action and firing rate unbalances can be instantly identified. The major equipment items for the fuel control system are given in Appendix A.

General Experience

The burner firing rate controls were satisfactory. The individual burner combustion air pressure gauges which were installed in the control room provided excellent control feedback information. These pressure gauges quickly indicated any control problems such as sticking actuators or maladjusted valve linkages. The diaphragm actuators were very durable in the sever environment.

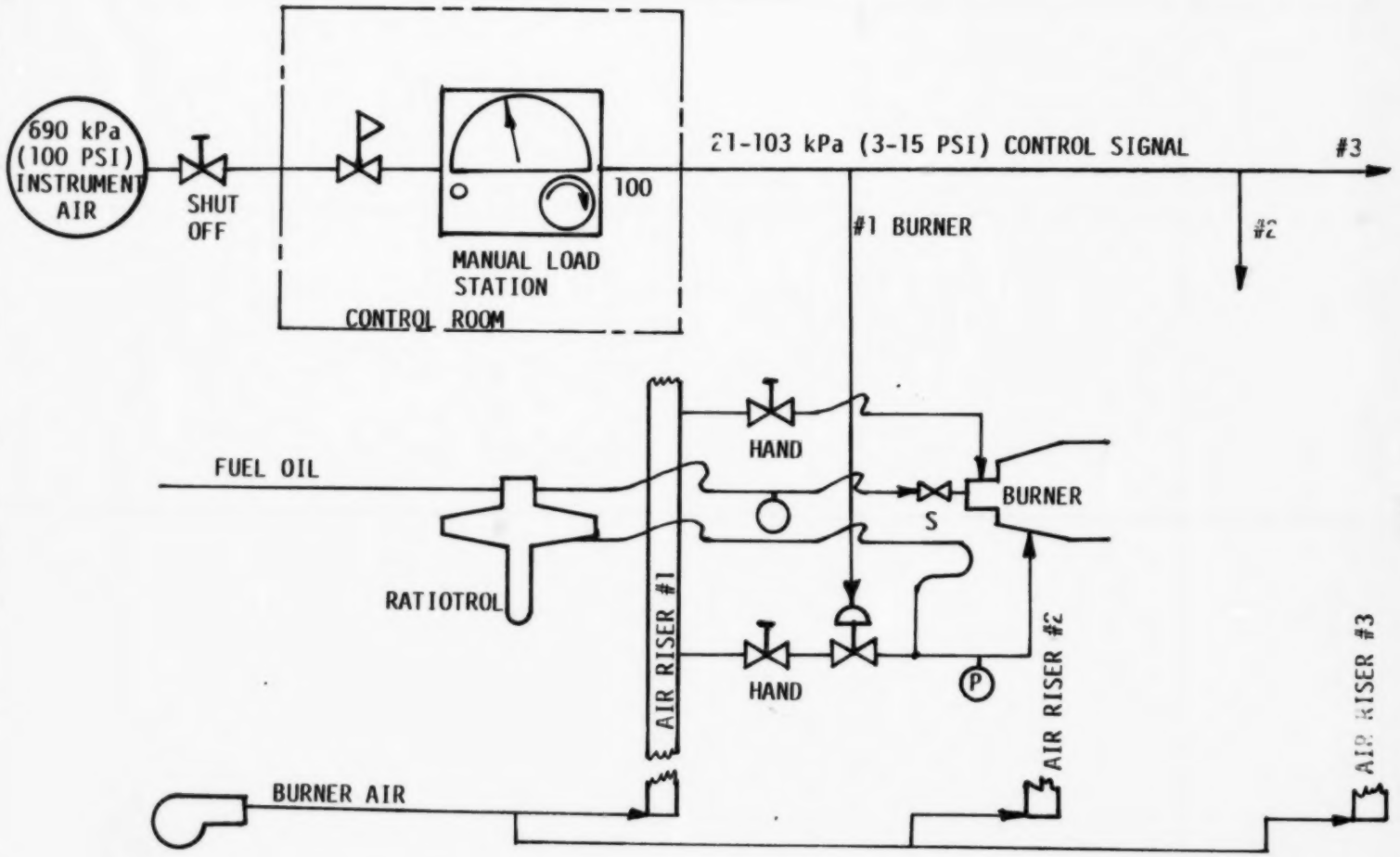

Figure 21. Remote Fuel Flow Control System Schematic

AIR CONTROL SYSTEM

Concept Selection

The incinerator air remote control system improved control of incinerator airflow. As shown in Figure 22, this system includes the following major elements:

- Hearth No. 8 airflow control
- Draft control
- Cooling air pressure relief

Hearth No. 8 Airflow Control

The incinerator open area was originally varied only by manual adjustment of peep holes and doors. New airflow controls were installed to allow variation of incinerator open area and airflow from the incinerator control room. The airflow controls were installed on the bottom hearth (No. 8) to allow maximum heat transfer from incinerator ash to the combustion air, and to provide maximum distance for the air inflow to distribute uniformly prior to the combustion hearth, located higher in the incinerator.

The 8 hearth airflow control duct was sized for an incinerator operating range from 4.5 to 7.3 wet metric tons (5 to 8 wet tons) per hour. This maximum exceeds the design load of 6.4 metric tons per hour (7 tons per hour). A large feed rate range was selected so that the airflow controls would not be a limiting factor in normal incinerator operation.

The 8 hearth air duct was sized on the basis of measured and calculated incinerator airflow distributions, verified by measured excess air, as reported in detail in Ref. 1. Typical airflow calibration results, shown in Figure 23, indicate that the internal calculated airflows are sufficiently close to actual airflows to allow air duct sizing.

The airflow requirements over the 4.5 to 7.3 wet metric tons per hour (5 to 8 wet tons per hour) operating range are shown in Table 3. To provide a very wide airflow range requirement, a low (but attainable) fuel consumption of 17 l/wet metric ton (4 gal/wet ton) was required for the 4.5 wet metric tons per hour (5 wet tons/hour) low feed rate, and a high fuel use of 38 l/wet metric ton (9 gal/wet ton) was required for the 7.3 wet metric tons per hour (8 wet tons/hour) high feed rate. As shown in Table 3, the incinerator airflow requirements on this basis, with 33% excess air, ranges from 1.66 to 2.95 kg/sec (3.66 lb/sec to 6.50 lb/sec). The airflow distributions at the minimum and maximum feed rate conditions are shown in Figure 24. These distributions reflect use of 6 hearth burners only at low feed rate, and the use of 4 and 6 hearth burners at high fire and high feed rate. As shown in Figure 24, the low feed rate airflow requirement is essentially met with the new 8 hearth air duct completely closed. All center shaft cooling air may still be employed at this low feed rate condition. On this basis, no remote controls were installed on the cooling air return system.

As shown in Figure 24, the high feed rate condition requires an 8

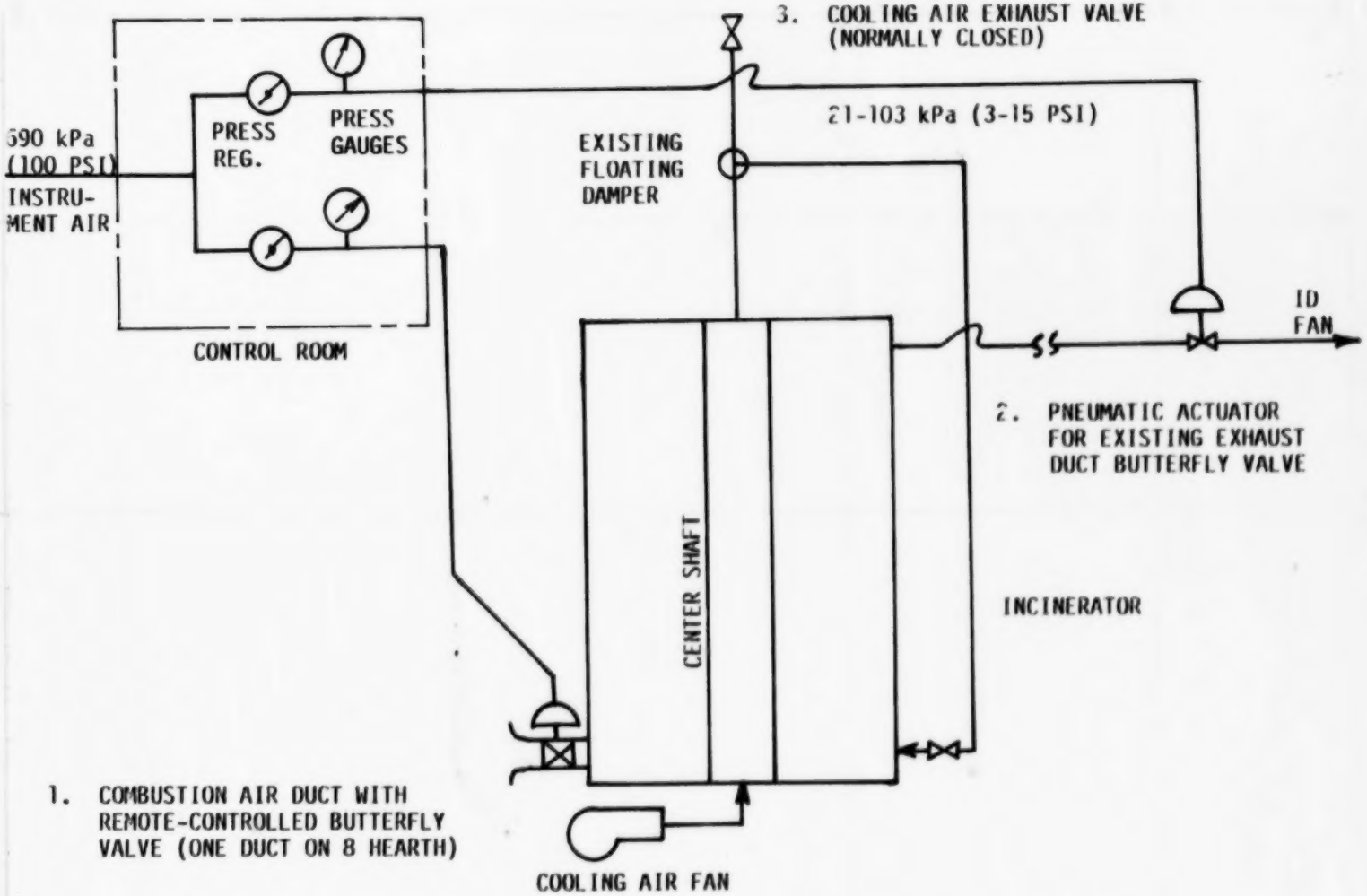

Figure 22. Incinerator Airflow Control System Schematic

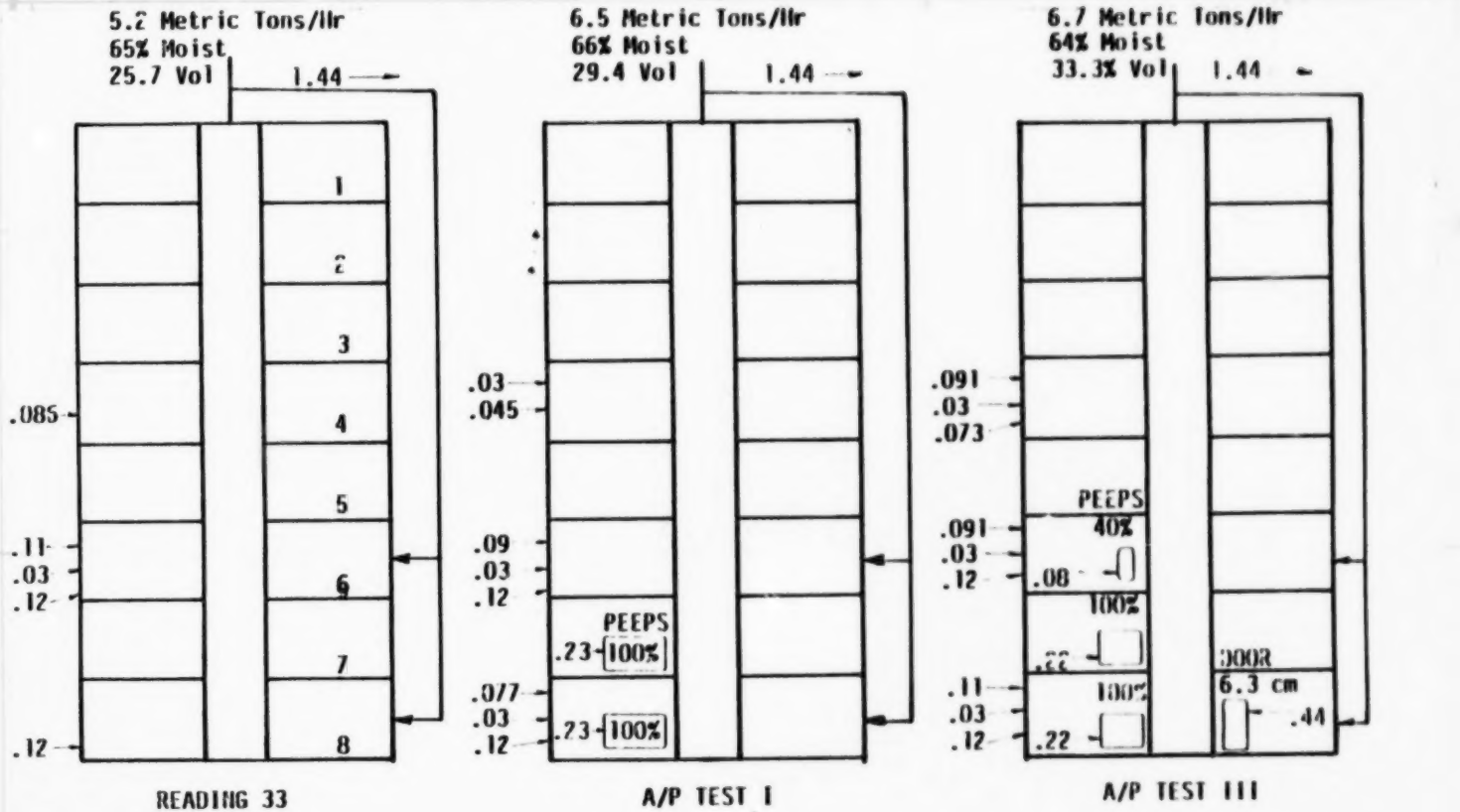

Figure 23. Typical Incinerator Airflow Distributions Confirmed by Exhaust Gas Analysis

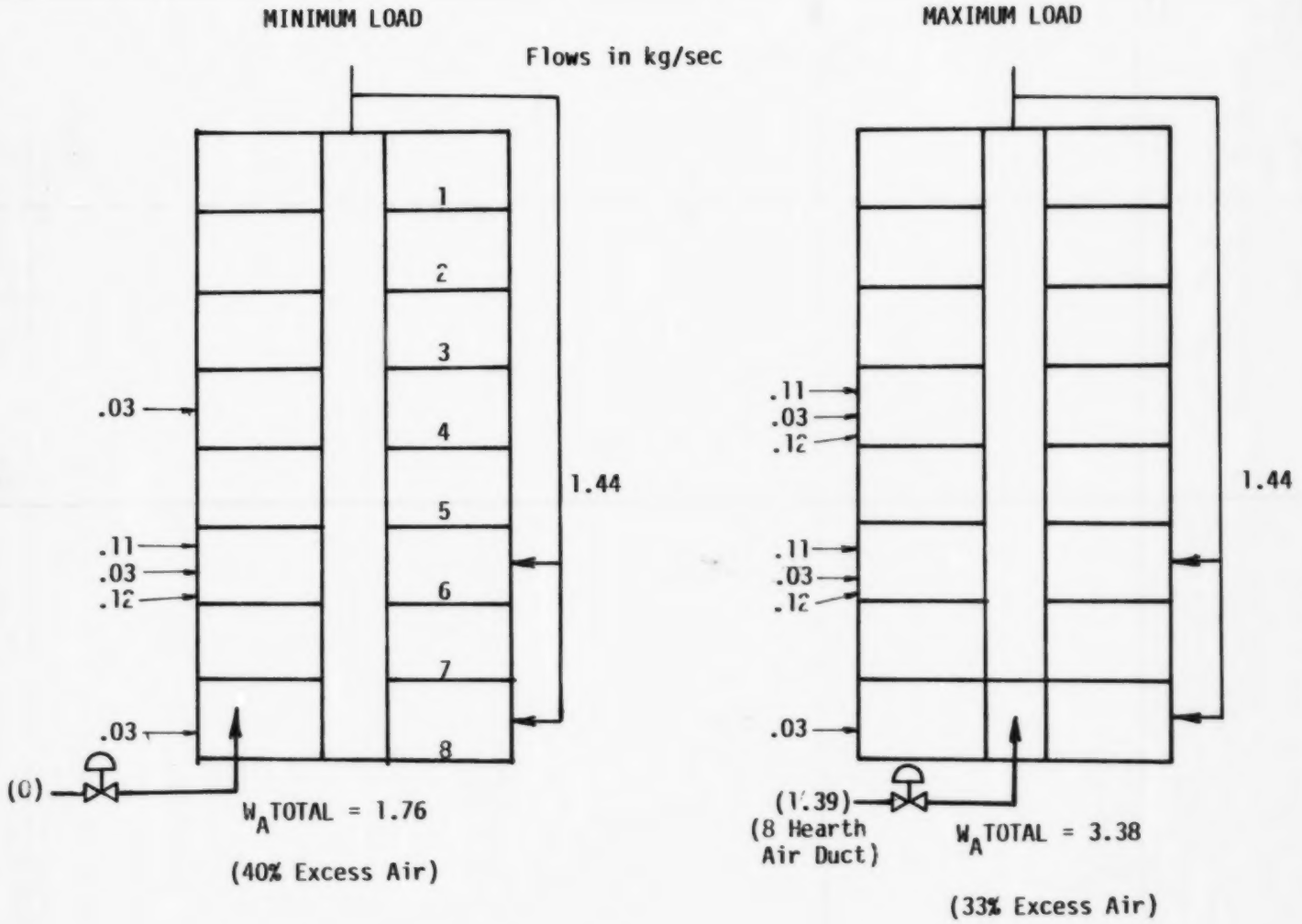

Figure 24. Incinerator Air Flow Requirements at Minimum and Maximum Loads

TABLE 3. INCINERATOR AIRFLOW REQUIREMENTS

Item	Minimum	Maximum
Feed Rate	4.5 Metric Tons/Hr (5 Tons/Hr)	7.3 Metric Tons/Hr (8 Tons/Hr)
Moisture	65%	65%
Volatile	30%	30%
Oil Consumption	16.7 Liters/Metric Ton(4 Gal/Wet Ton)	37.5 Liters/Metric Ton(9 Gal/Wet Ton)
Stoichiometric Volatile Air (1)	.27 kg/sec (0.59 lb/sec)	.97 kg/sec (2.14 lb/sec)
Stoichiometric Volatile Air (2)	.99 kg/sec (2.17 lb/sec)	1.57 kg/sec (3.46 lb/sec)
Total Stoichiometric Air	1.27 kg/sec (2.76 lb/sec)	2.54 kg/sec (5.60 lb/sec)
Air @ 33% Excess	1.66 kg/sec (3.66 lb/sec)	3.38 kg/sec (7.45 lb/sec)

(1) @ Oil = $CH_{1.25}$

(2) @ Sludge Volatile = $CH_{1.61}O_{.46}N_{.05}$

hearth airflow of 1.4 kg/sec (3.07 lb/sec). An 8 hearth air duct was therefore sized for this flow, using the following airflow equation (Ref. 1), assuming standard pressure, and 70°F air:

$$W_A = .0508\ A\ (P_T - P_S)$$

where

W_A = Airflow (kg/sec)

A = Ideal area (cm^2)

$(P_T - P_S)$ = Draft (kPa)

A bottom hearth draft of .055 kPa (0.22 in H_2O) was employed, based on Ref. 1 data for a low top hearth draft of 0.017 kPa (0.07 in H_2O). On this basis required duct diameter is 39.4 cm (15.5 inches). A 40.6 cm (16 inches) diameter duct was selected. If a more reasonable fuel consumption of (6.5 gal/ton) is achieved, then the 8 hearth duct can supply sufficient air for a feed rate of 8.17 metric tons/hour (9 tons/hour). Of course additional air beyond the capability of the 40.6 cm (16 inches) 8 hearth duct may be added by manually opening 8 hearth peep holes and/or doors.

The mechanical design for 8 hearth damper was a 40.6 cm (16 inches) heavy-duty round butterfly control damper bolted to a 40.6 cm (16 inches) schedule 40 pipe installed in the incinerator. A bellmouth inlet was installed on the butterfly damper to provide a stiff structure and a high discharge coefficient. The butterfly valve was actuated by a diaphragm air motor. The control signal range was 21-103 kPa (3-15 psi). The controls were set up to be fail-safe, i.e., zero air pressure closes the butterfly valve. The diaphragm actuator and manual load stations were the same as used for the burner controls.

Draft Control

The incinerator airflow rate is primarily changed by the exhaust system butterfly damper located just upstream of the ID fan. Movement of this damper changes system characteristics and fan airflow. A change in incinerator open area generally changes incinerator draft such that actual airflow change is minimal. A change in incinerator open area such as a change in exhaust damper setting is required to return the system to previous incinerator draft. In order to accomplish manual remote control, a pneumatic diaphragm actuator was installed on the existing 50.8 cm (290 inches) draft control damper. The diaphragm actuator and load station were the same as used for the burner firing rate controls with the control signal range again being 21-103 kPa (3-15 psi).

The South Incinerator Building incinerators did not have draft control dampers immediately upstream of the ID fans. Consequently, these dampers were fabricated in-house and installed. Control was the same as described for the North Incinerator Building.

Cooling Air Pressure Relief

The original incinerator system had a weighted "pop" damper to vent the cooling airflow to the atmosphere if the cooling air return dampers on 6 and 8 hearth were closed. In principle, this is satisfactory. Unfortunately, a large amount of cooling air escaped through the cooling air exhaust stack when the 6 and/or 8 hearth hearth cooling air return dampers were open. This cooling air is at 300°F and therefore its loss to the atmosphere is an energy loss that must be compensated for by burning additional auxiliary fuel.

In order to minimize this energy loss, a pressure relief damper was installed on the cooling air exhaust stack. A 50.8 cm (20 inches) multi-bladed pressure relief damper was used. The damper was fitted with an adjustable weight to provide a damper opening pressure in a range of 0.25 to 0.75 kPa (1-3 inches of water).

General Experience-Airflow Control System

The 8 hearth air damper control system provided very sensitive airflow control over the design load range.

Draft control was possible too within approximately 0.005 kPa (0.02 inches of water). At times, control range was a problem with this damper. The damper (installed prior to this program) had excessive leakage in the closed position causing excessive incinerator draft at low load conditions. At such times, the incinerator exhaust breech had to be partly opened to reduce draft to the required levels. This control range problem can be overcome through use of a low leakage damper.

The cooling pressure relief damper reduced unwanted cooling air leakage by approximately 50%. However, the residual cooling air leakage was still significant. The leakage flow resulted from gaps in this damper in the closed position. The measured cooling air duct pressures suggested that leakage to the atmosphere increased when only one of the cooling air return dampers was open. The leakage flow was calculated according to the following airflow equation, (Ref. 1):

$$W = .0388AC_d\ (P_T - P_S)P_S/T$$

where

W = Airflow (kg/sec)

A = Area (cm^2)

C_d = Discharge coefficient

$(P_T - P_S)$ = Dynamic head (kPa)

P_S = Static Pressure (98.85 kPa (395 in H_2O) @ plant elevation)

TYPING GUIDE SHEET

T = Temperature ($422K_1$ 760 R)

On this basis, the estimated leakage flow for each damper is 0.35 kg/sec (0.78 lb/sec) when only one cooling return damper is open. On the basis of five incinerators and 80% burner heat utilization efficiency (due to an exhaust temperature of 371°C (700°F), and $1.00/gallon oil, the annual energy cost for this leakage is $62,400 per year. This is approximately 3% of Indianapolis' baseline fuel consumption. It is undoubtedly cost-effective for Indianapolis to further reduce this energy loss.

CONTROL ROOM

All instrument readouts and controls were installed in the control rooms. In the North Incinerator Building, the existing control panels were modified to accommodate the new installations. The improved control installation is shown in Figure 25. The changes were accomplished with essentially no disruption of incinerator operations. The oxygen analyzer calibration system was end-mounted on one instrument cabinet with a manifold system for all four analyzers. The filter room feed rate recorder was also to be end-mounted in an existing filter room control panel.

The South Incinerator Building originally did not have a separate incinerator control room or a control panel that could be expanded as was done in the North Incinerator Building. Therefore, two new incinerator control cabinets similar to the North Incinerator Building control cabinets were obtained. These were installed in a new control room similar to the North Incinerator Building.

INSTRUMENTATION AND CONTROL EQUIPMENT COST SUMMARY

The total cost for the major components of the new instrumentation and control system was $118,043, or $18,278 per incinerator in 1979 dollars. Table 4 shows the cost breakdown for each of the major components of the five systems. The sludge flow measurement system was only installed on the four incinerators in the North Building as previously explained. Engineering and other installation costs increased the total cost to an estimated $28,000 per incinerator.

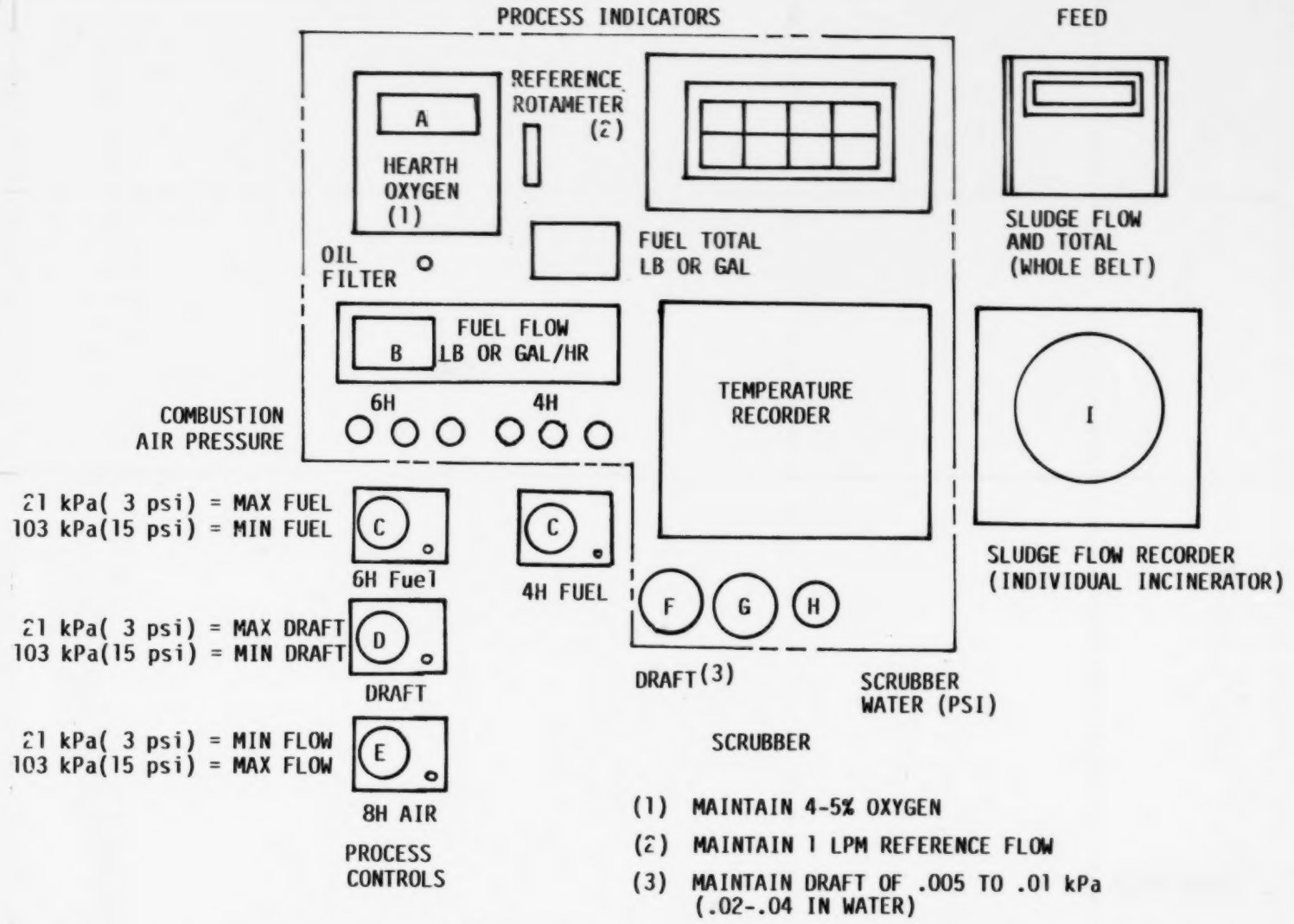

Figure 25. New Incinerator Control Panel Design

TABLE 4. EQUIPMENT COST SUMMARY

Sludge Flow Measurement System		
Four Weigh Scales		$ 19,540
Two Processor Units		4,260
Six Circular Chart Recorders		3,930
Four Factory Mounted Idlers		440
	Sub-Total	$ 28,170
Fuel Flow Measurement System		
Eight Fuel Flow Rate Meters		$ 20,160
Eight Mass Flow Indicators		6,720
Eight Fuel Flow Totalizers		5,376
Eight Fuel Filters and Replacement Sets		624
	Sub-Total	$ 32,880
Fuel Flow Control System		
Forty-Eight Diaphragm Actuators		$ 9,914
Forty-Eight Butterfly Control Valves		3,930
Sixteen Manual Load Control Stations		3,728
Sixteen Pressure Regulators		582
Forty-Eight Fuel Pressure Gauges		588
Forty-Eight Combustion Air Pressure Gauges		588
Air Supply System Filter and Elements		344
Shutoff Valves and Miscellaneous		493
	Sub-Total	$ 20,167
Oxygen Analysis System		
Eight Zirconium Oxide "In-Situ" Oxygen Analyzers		$ 25,520
Eight Flow System Components		1,934
	Sub-Total	$ 27,454
Air Flow Control System		
Eight Damper and Bellmouth Flange Assemblies (Hearth #8)		$ 1,944
Eight Manual Load Control Stations		1,864
Eight Damper Diaphragm Actuators		1,652
Eight Draft Damper Diaphragm Load Stations		1,864
Eight Cooling Air Exhaust Pressure Relief Dampers		2,048
	Sub-Total	$ 9,372
TOTAL ALL SYSTEMS FOR 8 INCINERATORS		$118,043

SECTION 7

INCINERATOR OPERATING MODE

Incinerator fuel reduction requires the following:

1. Instrumentation and controls to physically allow operation in the optimum mode
2. Definition of optimum incinerator operating mode
3. Operator training

The instrumentation and controls required in Indianapolis, described in Section 4, were installed to meet the hardware requirements.

OPTIMUM OPERATING MODE

The optimum incinerator operating mode for Indianapolis was established from theoretical analysis, analysis of parametric test data and by operational trial runs, as discussed in Ref. 1. This optimum operating mode was summarized to serve as the formal training material for the operators. The Indianapolis operating mode is shown in Figures 26 through 31. The operating mode for other cities could vary substantially due to equipment, operation, and sludge cake differences.

Figure 25 summarizes the control panel with the new instruments and controls. They are divided into the following groups:

- Feed
- Process Indicators
- Process Controls

Feedback information for the process controls is provided by the process indicators. Feedback information for the fuel control includes the individual burner combustion pressures and the total fuel flow rate. The incinerator draft is the feedback for the draft damper controller. The feedback for the 8 hearth air damper is the incinerator oxygen level.

Figure 26 shows the summarized optimum operating procedure. The key points of the procedure are:

1. Maintain steady feed rate. Optimum operation is very difficult when the sludge load varies. The individual weigh scales and the feed rate recording in the filter room provide the additional information required to maintain a more constant sludge feed rate.

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1. MAINTAIN STEADY LOAD (Instrument "I" - Figure 25)

2. MAINTAIN DRAFT OF .005 - .010 kPa (.02 - .04 IN WATER) (Instrument "F")

   - CONTROL ROUTINELY WITH DRAFT CONTROL (Instrument "D")
   - USE SPIN DAMPER IF REQUIRED (Coarse Control)

3. MAINTAIN 4-5% OXYGEN (Instrument "A" - Figure 25)

   - CONTROL WITH 8 HEARTH AIR CONTROL (Instrument "E")

4. MAINTAIN SLUDGE COMBUSTION ON HEARTH 6

   - CONTROL SLUDGE BURNING LEVEL BY FUEL FLOWRATE (Instrument "C")
   - USE FUEL FLOW GUIDELINES AND EXPERIENCE TO PREVENT TEMPERATURE CYCLING

5. MINIMIZE FUEL TO HEARTH 4 BURNERS

   - LIMIT MAXIMUM TEMPERATURE TO 840-900^{o}C (1550-1650^{o}F) TO PREVENT CLINKER FORMATION

Figure 26. General Operating Procedure

FEED RATE	• INSIST ON STEADY 6.4 METRIC TONS/HR/INCINERATOR (7 TONS/HR), OR AS DIRECTED.
CENTER SHAFT	• USE 0.6 RPM. INCREASE SPEED ONLY IF REQUIRED TO KEEP SLUDGE LEVEL BELOW RABBLE ARM. CHECK ALL HEARTHS AS REQUIRED.
COOLING AIR	• GENERALLY RETURN COOLING AIR TO HEARTH 8 ONLY. WASTE COOLING AIR TO STACK ONLY AS REQUIRED TO MAINTAIN OXYGEN AT VERY LOW LOAD. CONFIRM ROOF DAMPER VENTING ACTION AT ONCE IN THIS CASE.
DOORS/PEEPS	• NORMALLY CLOSED TIGHT ON ALL LEVELS. OPEN DOORS/PEEPS ONLY ON HEARTH 8 AS REQUIRED TO MAINTAIN 4-5% OXYGEN.
BURNERS	• GENERALLY USE HEARTH 6 BURNERS ONLY. CONTROL FUEL FLOW WITH HEARTH 6 FUEL CONTROL. HEARTH 6 BURNER MANUAL COMBUSTION AIR VALVES MUST BE WIDE OPEN.
	• IF MORE FUEL IS REQUIRED THAN CAN BE OBTAINED FROM HEARTH 6 BURNERS ALONE, ADD THIS FUEL ON HEARTH 4.
	• SENSITROLS - ADJUST INDIVIDUALLY TO MAXIMUM THAT GIVES NO SMOKE, THEN LEAVE ALONE.
	• ATOMIZING AIR - 100% OPEN ON FIRING BURNERS
	- 30% OPEN ON "OFF" BURNERS
	• COMBUSTION AIR - "AS REQUIRED" ON FIRING MANUAL BURNERS
	- 100% OPEN ON FIRING HEARTH 6 BURNERS
	- CLOSED ON "OFF" BURNERS
	• REGISTERS - 100% OPEN ON FIRING BURNERS
	- CLOSED ON "OFF" BURNERS

Figure 27. Specific Settings - Normal Operation

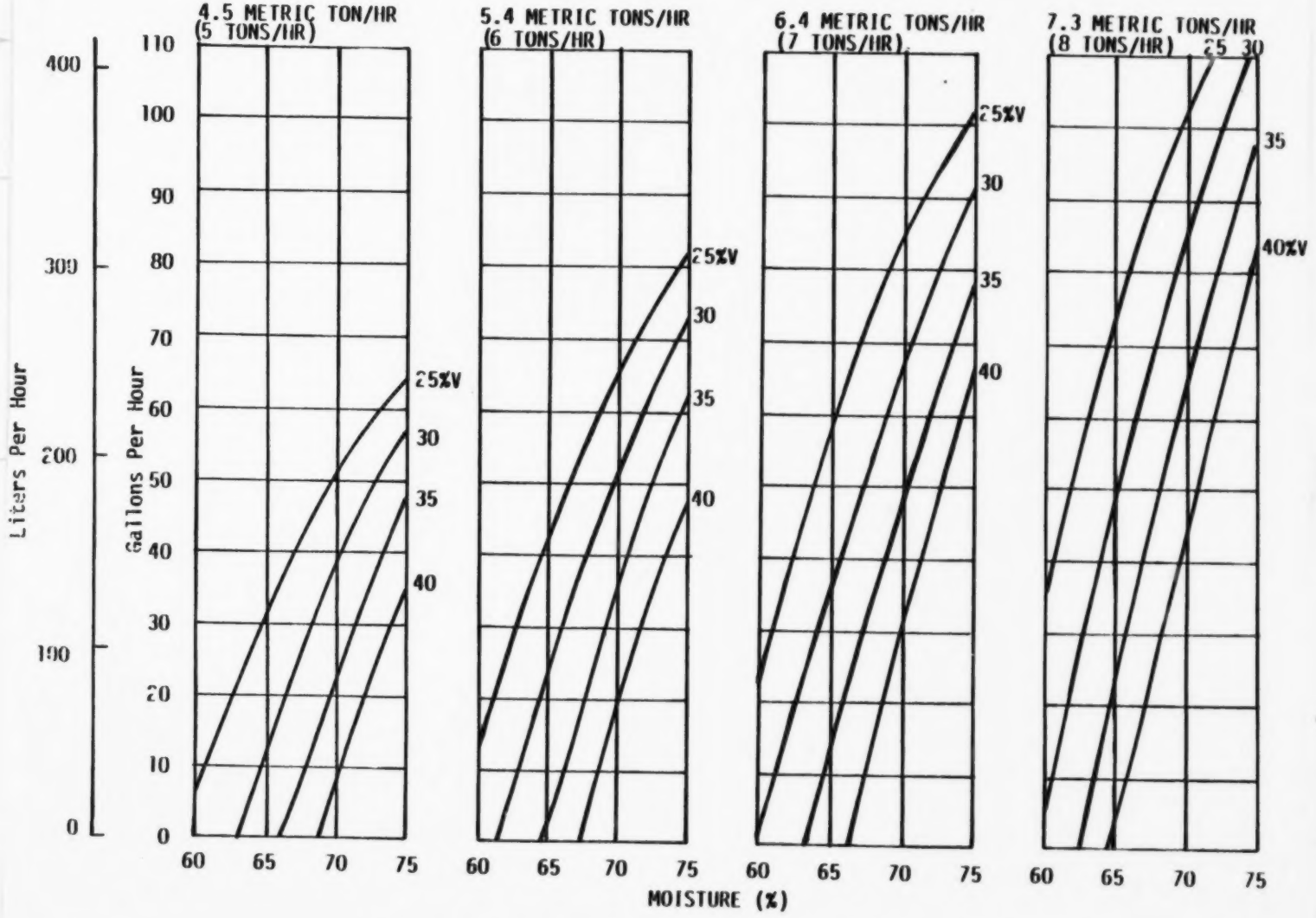

Figure 28. Fuel Flow Guidelines (Liters of Oil/Hour)

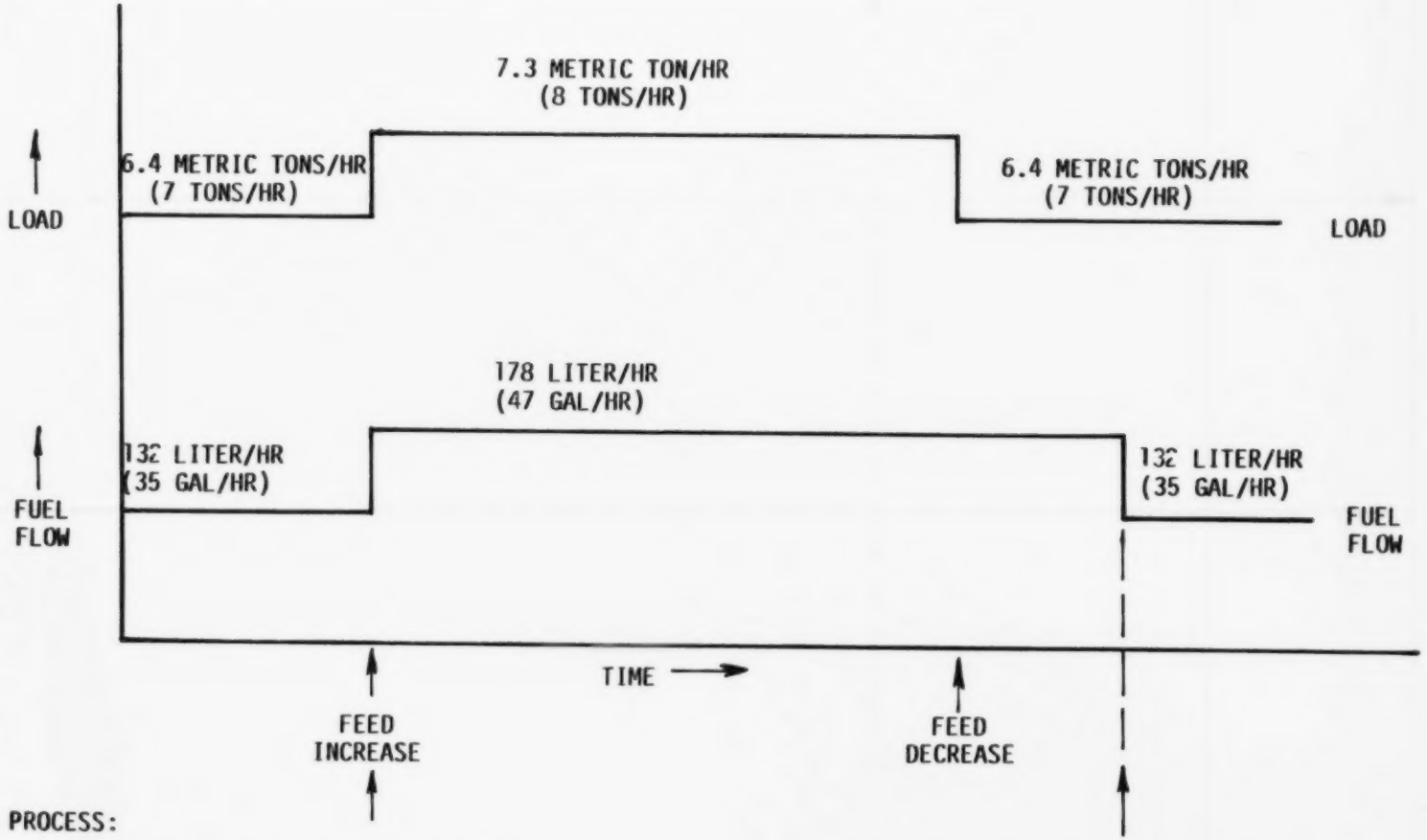

Figure 29. Special Operating Procedure for Unsteady Load

CAUSE: INSUFFICIENT SLUDGE DRYING RATE RELATIVE TO FEEDRATE

REMEDIES: (1) INCREASE FUEL, (2) REDUCE FEEDRATE, OR BOTH

IN ALL CASES REDUCE FEEDRATE TO NORMAL IF REQUIRED.

"MILD DROP" - INCREASE FUEL AS REQUIRED TO STABILIZE COMBUSTION ON 6 HEARTH

"MODEST DROP" - 1. INCREASE 6 HEARTH FUEL AS BEFORE

2. LIGHT 8 HEARTH BURNERS AS REQUIRED TO COMPLETE SLUDGE COMBUSTION INSIDE INCINERATOR

3. TURN OFF 8 HEARTH BURNERS AS FIRE CLIMBS TO 6 HEARTH

"SEVERE DROP" - 1. SAME AS ABOVE PLUS REDUCE SLUDGE LOAD FOR 30 MINUTES BY

- DIVERTING PART OF LOAD TO "HEALTHY" COMPANION INCINERATOR

or - REDUCTION OF SHAFT SPEED

or - REDUCTION IN FILTER OUTPUT

2. INCREASE LOAD TO NORMAL WHILE MAINTAINING COMBUSTION ON 6 HEARTH

"LOST IT, SLUDGE IN BASEMENT" - 1. SHUT OFF INCINERATOR FEED

2. STOP CENTER SHAFT

3. DRY SLUDGE

4. START SHAFT - MOVE FIRE UP TO 6 HEARTH

5. REESTABLISH FEED - WORK TOWARD STEADY STATE

Figure 30. Special Procedures for Dropping Combustion Zone

RISING FIRE

CAUSE: EXCESSIVE SLUDGE DRYING RATE RELATIVE TO FEEDRATE

REMEDIES: (1) REDUCE FUEL, (2) INCREASE FEEDRATE, OR BOTH

IN ALL CASES INCREASE FEEDRATE TO NORMAL IF REQUIRED

"MILD RISE" - 1. DECREASE FUEL AS REQUIRED TO STABILIZE COMBUSTION ON 6 HEARTH

"SEVERE RISE (BURNOUT)" - 1. SHUT OFF ALL FUEL

2. STOP SHAFT TO CONTROL TEMPERATURE AND TO PRESERVE DRY SLUDGE FUEL FOR WHEN LOAD INCREASES

STANDBY

EMPLOY WHEN THERE IS A FEED INTERRUPTION

OBJECTIVE: MINIMUM FUEL CONSUMPTION

1. SLOWLY BURN OUT DRIED SLUDGE BY MINIMUM SHAFT MOTION AND AT LOW OXYGEN (1%)
2. RIG FOR MINIMUM HEAT LOSS
   - DRAFT = .005 kPa (.02 IN WATER)
   - ALL OPENINGS - CLOSED TIGHT
3. ADD 6 HEARTH FUEL TO MAINTAIN TEMPERATURE OF 540°C (1000°F) ON 6 HEARTH

Figure 31. Special Procedures for Rising Combustion Zone and Standby

2. Maintain draft of 0.005-0.01 kPa (0.02-0.4 inches of water). Optimum operation employs a constant low draft on the 1 hearth level. This minimizes upper hearth air leakage inflow while preventing room smoke from the drop chute and upper hearths. The draft damper controller provides sensitive control on this variable. Coarse control is provided when required by the scrubber spin damper or exhaust breeching doors.

3. Maintain 4-5% oxygen level. This oxygen level insures sufficient excess air on the combustion level to prevent smoke emission while minimizing incinerator heat loss to excessive airflow. This variable is controlled by the new 8 hearth air damper and its pneumatic control.

4. Maintain sludge combustion on 6 hearth. Burning on the 6 hearth level insures that the incinerator ash is sufficiently cool when discharged into the ash hopper. It also insures that a reasonable fraction of the available incinerator hearth area is being used for sludge drying. This variable is controlled by burner firing rate. Increased fire increases drying rates which moves the combustion zone up in the incinerator.

5. Minimize fuel to 4 hearth burners. Burner heat applied at or below the sludge combustion zone provides improved drying on all drying levels. The 4 hearth burners would not provide improved 5 hearth drying so it is best to not use these burners unless required due to insufficient firing rate availability from the 6 hearth burners. In rare cases, the 4 hearth burners might also be used to limit maximum temperatures to 900°C (1650°F) in order to prevent clinker formation.

Figure 27 shows the specific settings of all incinerator variables for normal operation.

Figure 28 shows fuel flow guidelines in liters/hour (gals./hr) for various incinerator feed rates and sludge cake moisture and volatile contents. These required fuel flows were generated using the dynamic incinerator analytical computer model described in Section 5. This information provides the operator with an estimate of required fuel flow for any feed condition. It is also of great benefit in estimating the required fuel flow changes when feed conditions change.

Figure 29 illustrates general procedures to be used for unsteady feed rate. As sludge feed rate increases, the fuel rate must go up at once in order to dry the increased sludge load in time for combustion. The required increase may be estimated from Figure 28. As sludge feed rate decreases, the fuel rate is reduced to maintain steady combustion on a given hearth level. The fuel flow reduction again may be estimated from Figure 28. The fuel flow reduction would be applied after a delay of approximately 30 minutes in order to complete processing of the large sludge load present in the incinerator at the time of the feed rate reduction.

The procedures for a dropping sludge fire are shown in Figure 30. A dropping fire indicates an insufficient sludge drying rate relative to the sludge feed rate. The remedy, as shown in Figure 30, is increased burner

firing rate and/or reduced feed rate.

The procedures for a climbing fire are shown in Figure 31. A climbing fire indicates excessive sludge drying rate relative to the sludge feed rate. The remedy is to reduce burner firing rate. The climbing fire can result in a severe "burnout". In such cases, all burner fuel would be shut off and the centershaft stopped to reduce the burning rate.

Figure 31 also shows the settings for "standby" periods (no sludge feed). Following combustion of all sludge, the incinerator is rigged for minimum heat loss by closing all openings, including the cooling air returns and operating at minimum draft of 0.005 kPa (0.02 in H_2O). Sufficient fuel is added to maintain 540 ^{o}C (1000 ^{o}F) temperature on 6 hearth.

OPERATOR TRAINING PROGRAM

Incinerator fundamentals and the fuel-efficient incinerator operating mode were taught to all operators and supervisory personnel in classroom sessions. All operators and supervisors were provided an incinerator operating manual, containing Figures 26 through 31 as previously discussed. Retention of this material was assessed by test. The classroom instruction alone was not sufficient to accomplish routine incinerator operation in the optimum operating mode. On-the-job training was also required.

The North Incinerator Building air pollution compliance tests were supervised by project combustion engineers to assure that the incinerators were operated in the optimum operating mode. These special tests essentially provided further on-the-job training for the Indianapolis operators. The results of the air pollution compliance tests are described in Section 9.

A two-day fuel consumption demonstration test was also conducted by project combustion engineers to assess the new instruments and controls and to demonstrate again the fuel reduction possible in the optimum operating mode. This special test essentially provided another four shifts of on-the-job training. Results from this special test are presented in Section 8.

The net result of all this activity was that significant operational improvements were accomplished as discussed in Section 8.

SECTION 8

PERFORMANCE DEMONSTRATION TEST RESULTS

Two performance demonstration tests were conducted to determine the fuel reduction achieved from upgrading the incinerator control systems and using a more fuel efficient operating mode. A full plant scale operational test was made over an eight month period to determine the fuel reduction in routine operations. During the last month of the full scale demonstration period, an additional performance test was conducted with ICFAR combustion engineers directly operating three incinerators for a continuous 48 hour period to determine the optimum fuel efficiency of the new system.

OPERATIONAL DEMONSTRATION TEST

The operational demonstration period was from November, 1980 through June, 1981. The baseline operational year used for comparison was 1977 since it was the last full calendar year of operations before any changes were initiated in the incinerator operating mode or control equipment. Plant operational records for both periods were used to obtain fuel consumption, load rates, incinerator operating hours, and sludge cake moisture and volatile data for comparative analysis. The principal measure used for comparing fuel consumption was the specific fuel consumption (SFC) defined as liters of oil per dry volatile metric ton of sludge cake incinerated. The specific fuel consumption is also directly related to the absolute ratio of sludge cake moisture to volatile content (kg/kg). An accurate comparison of specific fuel consumption must account and correct for the moisture to volatile ratio (M/V) of the sludge cake being incinerated to avoid a distorted comparison. For this reason, the relationship of the daily average specific fuel consumption and the sludge cake moisture to volatile ratio for the demonstration period was computed and compared to the same relationship recorded for the 1977 baseline operations to enable the specific fuel consumption comparisons to be made for a given sludge moisture to volatile ratio.

A least squares regression analysis was made for the SFC versus sludge cake M/V ratios for both time periods. The results of these analyses are shown in Figures 32 and 33 with the computed regression straight line drawn to reflect the overall changes observed. Figure 34 shows both lines for comparison along with the average for the two day ICFAR optimum fuel efficiency test. Table 5 shows the respective averages of the other operational variables for the two time periods.

As shown in Figure 34, the average sludge cake M/V ratio for the demon-

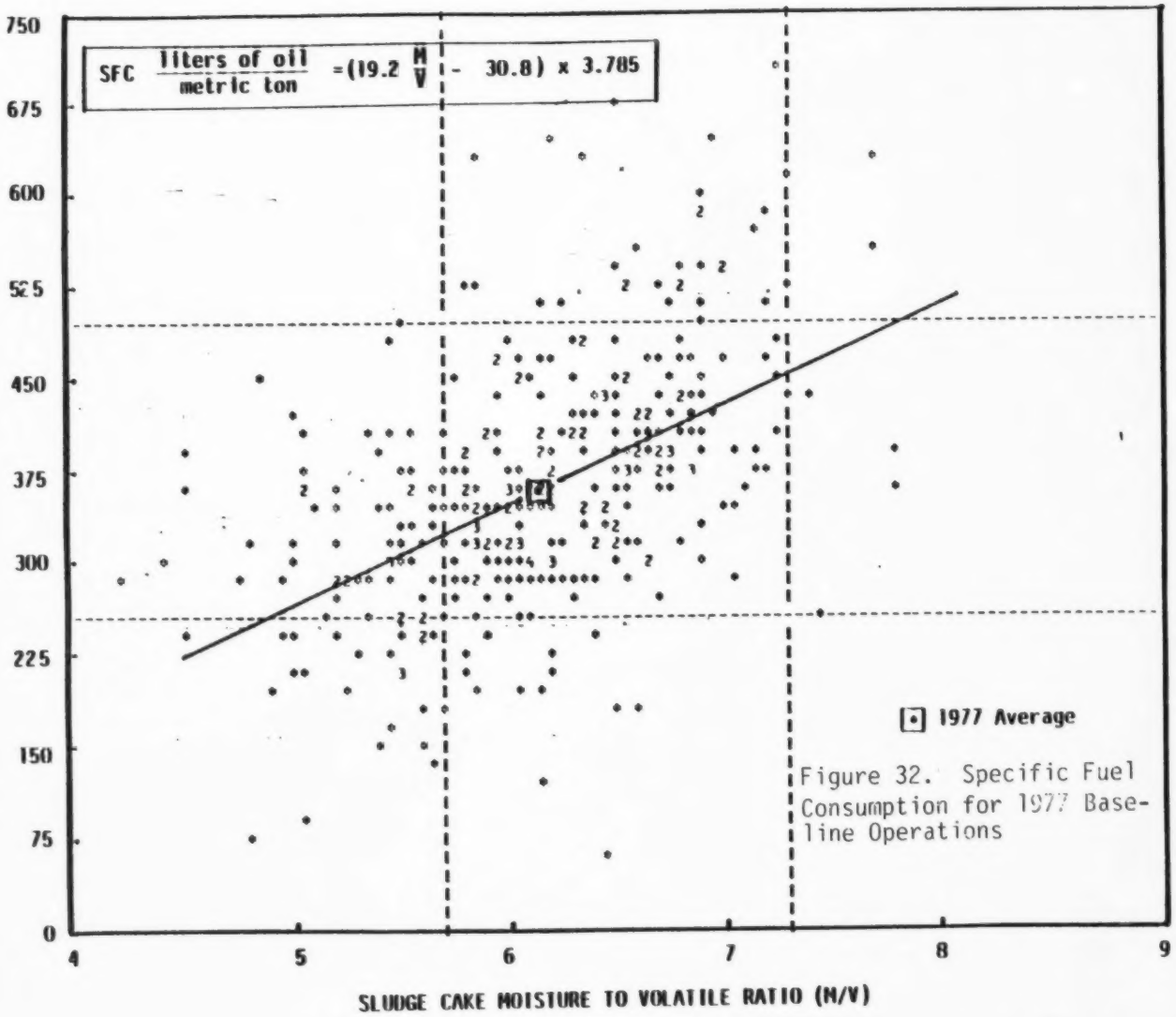

Figure 32. Specific Fuel Consumption for 1977 Baseline Operations

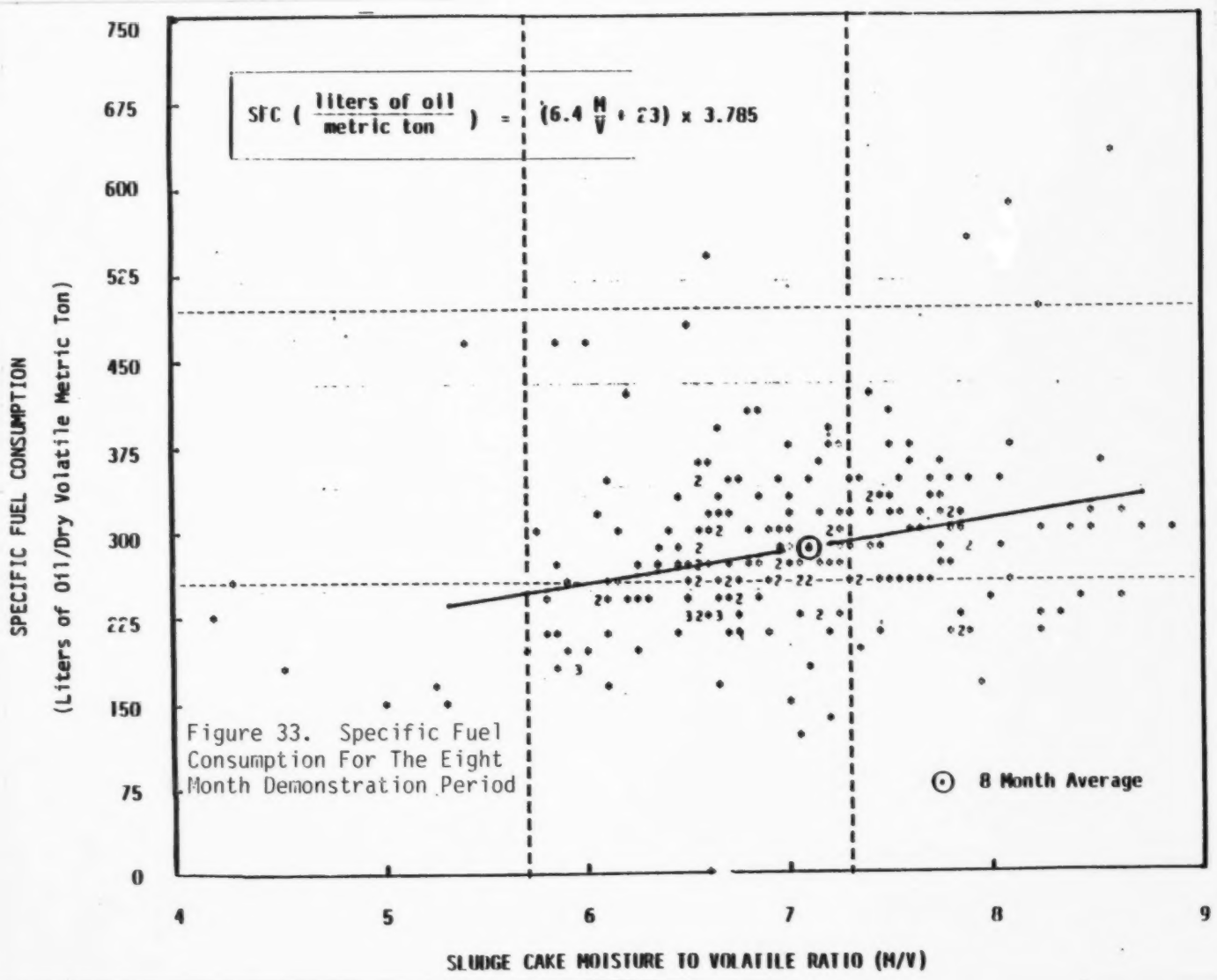

Figure 33. Specific Fuel Consumption For The Eight Month Demonstration Period

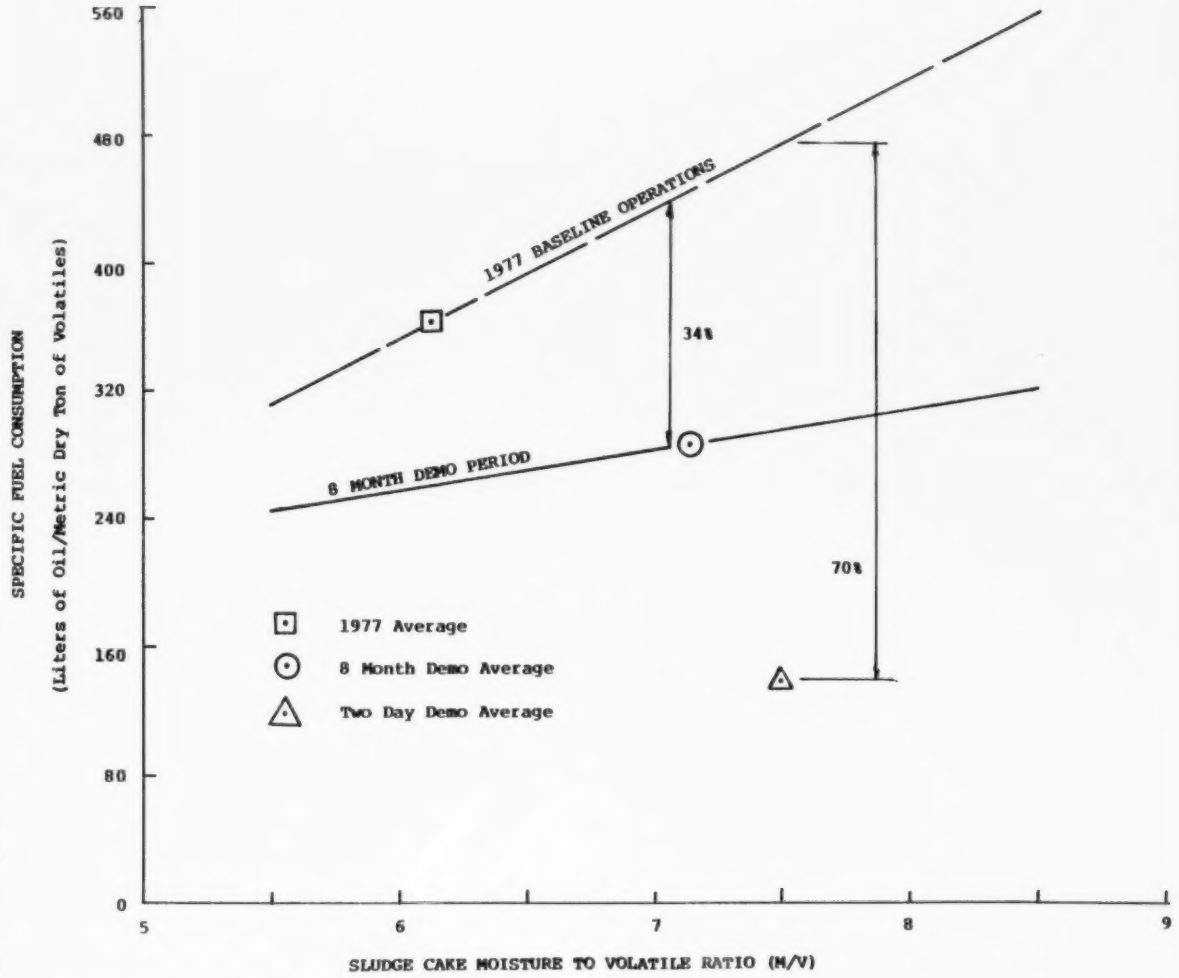

Figure 34. Specific Fuel Consumption Comparison

TABLE 5. DAILY AVERAGE VALUES OF KEY OPERATING VARIABLES FOR BASELINE YEAR AND DEMONSTRATION PERIOD

Operating Variable	DAILY AVERAGE VALUE 1977 (12 Months)	8 Month Demo Period	Percent Difference
Cake Load: Wet Metric Tons	767.8	817.3	+ 6.5
Dry Volatile Metric Tons	78.1	83.5	+ 6.9
Percent Moisture	64.1	71.7	+11.9
Percent Volatiles	29.6	37.3	+26
Moisture/Volatile Ratio	6.13	7.07	+15
Incinerator Hours	115	116	--
Filter Hours	168	254	+51
Load Rate: (Wet Metric Tons/ Incinerator/Hour)	6.76	7.04	+ 4

TABLE 6. COMPARISON OF SPECIFIC FUEL CONSUMPTION FOR VARIOUS SLUDGE CAKE M/V RATIOS

Sludge Cake M/V Ratio	SPECIFIC FUEL CONSUMPTION (Liters of Oil/Dry Volatile Metric Ton) 1977	8 Month Demo Period	Percent Difference
6.0	351.4	256.5	-27
6.5	391.4	269.8	-31
7.0	431.3	283.1	-34
7.5	471.3	296.4	-37
8.0	511.3	309.8	-39
8.5	551.2	323.1	-41

stration period was higher than in 1977 reflecting dewatering process changes that occurred between the two periods. The specific fuel consumption was reduced, as well as the basic relationship between SFC and sludge cake M/V ratio as reflected by the decreased rate of increase of SFC with M/V ratio. At the low M/V ratio of 6, the computed SFC difference was 27%, and at the high M/V ratio of 8.5, the difference was 41%. Table 6 shows the computed difference in SFC for various sludge cake M/V ratios. The SFC difference corresponding to the average sludge cake M/V ratio for the demonstration period was 34%. This result does not represent the full fuel reduction potential since four out of the eight incinerators were not fully equipped with the new control systems until three months after the demonstration period was started. Even so, the 34 percent demonstrated fuel reduction average represents annual fuel savings, or cost avoidance of over $900,000 per year based on current oil prices of $1.00 per gallon. The total estimated project cost was $260,000 giving a payback period of less than four months.

TWO-DAY OPTIMUM FUEL EFFICIENCY TEST

As an additional evaluation, a 48 hour incinerator performance test was conducted by the ICFAR engineers to determine the optimum fuel reduction possible using the new operating mode and control systems. Three incinerators were operated for 48 hours under normal operating conditions with the exception that the loading rates to the incinerators were extremely erratic during the test period making it a far more severe test of the equipment and operating technique than what would be experienced in normal routine operations when loading rates would not vary to the degree they did during this weekend test. The extreme variation of the load rates experienced are shown in Figure 35. In spite of the extreme load variations and also the high M/V ratios of the sludge cake, the fuel reduction as shown in Figure 34 was 70 percent below the 1977 baseline. This dramatic demonstration suggests further fuel reductions could still be achieved in routine operation through further training and equipment improvement efforts.

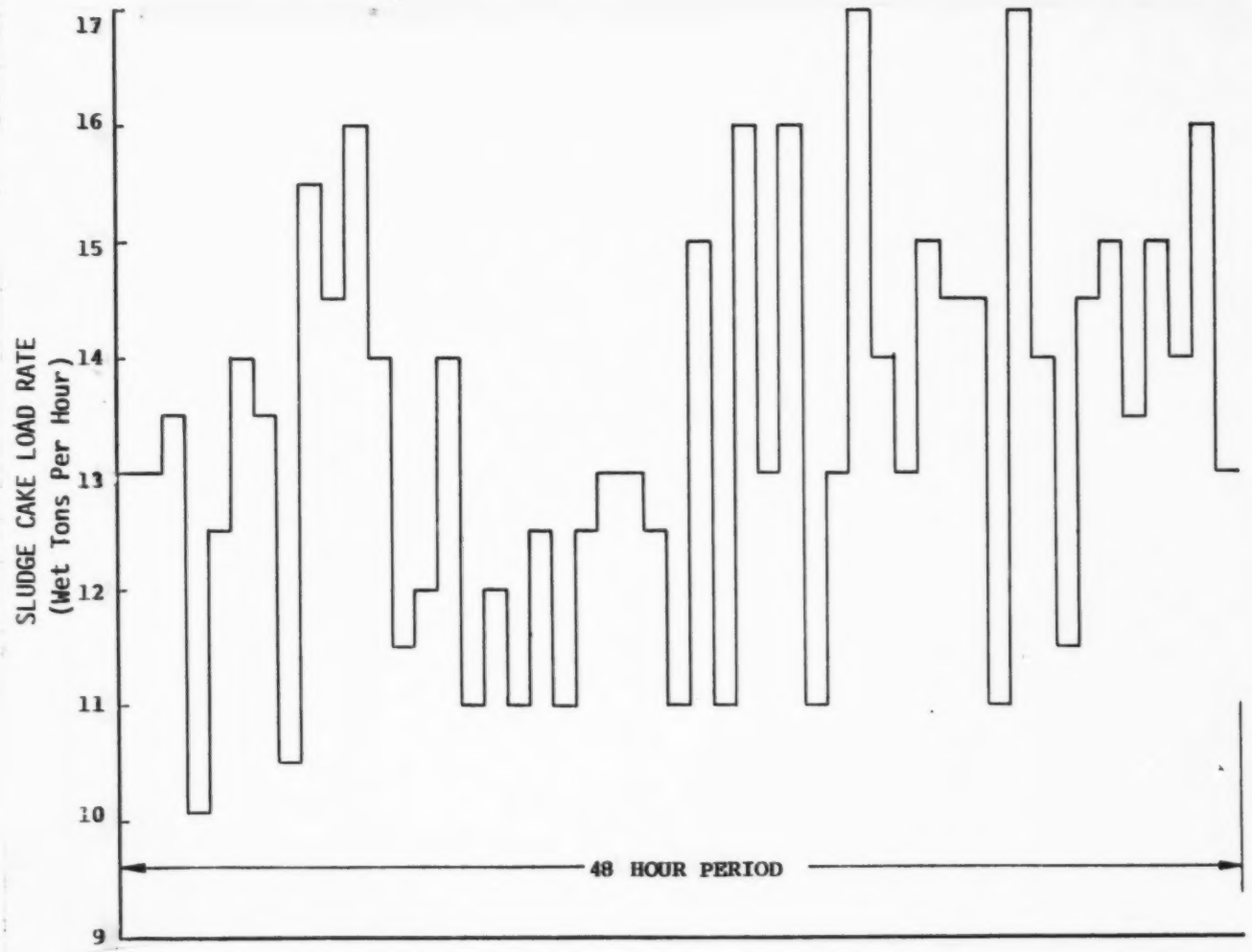

Figure 35. Sludge Cake Load Variation

SECTION 9

INCINERATOR PARTICULATE EMISSION TEST RESULTS

The impact of the new operating mode and control systems on incinerator particulate emissions was also assessed. As previously discussed, the Indianapolis incinerators are equipped with low energy type cyclonic stack gas scrubbers with no impingement trays for particulate removal. The incinerators had been tested prior to start of this project and had been found to be in violation of the particulate emission standard. The violation level measured was 0.60 gm of particulate/kg of dry exhaust gas, corrected to 50% excess air which was 100% above the allowable Indiana standard of 0.30 gm particulate per kg of dry exhaust gas. During the course of this project, Indianapolis agreed to a court ordered consent decree to correct the incinerator air pollution problem. At the time, the only proposed solution was the installation of high energy venturi type scrubber systems at an estimated cost of over $2 million. The ICFAR and Department of Public Works Engineering staffs then proposed a feasibility test be made to determine if the new incinerator operating mode would enable the incinerators to meet the particulate standard with the existing scrubber system. A feasibility test was then conducted on one incinerator using a qualified independent stack testing firm with the incinerator being operated in the new mode. The result of this test was an average measured particulate emission level of only 0.15 gm/kg of particulate of dry exhaust gas corrected to 50% excess air which was 50% below the 0.30 gm/kg standard.

On the basis of this result, Indianapolis then proceeded under the consent decree to officially test all eight incinerators as they became equipped with the new operating control systems under this project. All of the tests were conducted as official compliance tests. Shown in Table 7 and Figure 36 are the results of the eight incinerator tests. All eight incinerators, using the new operating mode and control systems, were brought into compliance with the standard. This result enabled the City of Indianapolis to avoid a $2 million bond issue that would have been required to retrofit the incinerators.

The results of these compliance tests and other parametric tests performed on the Indianapolis incinerators by the Stationary Sources Emissions Research Branch staff of EPA Research Triangle Park showed the incinerator operating mode having a very direct and significant effect on particulate emissions. This was a very significant by-product result of this project, not only in saving Indianapolis $2 million, but also in advancing the operational understanding of how the incinerator operating mode can critically affect particulate emissions with low energy type scrubber systems.

TABLE 7. OFFICIAL PARTICULATE COMPLIANCE TEST RESULTS FOR INDIANAPOLIS SLUDGE INCINERATORS

Incinerator Number	Particulate Emissions (gms/kg)*	Percent of Allowable Level+	Date of Test
1	0.2588	86	August 7-8, 1980
2	0.1740	58	March 19-20, 1981
3	0.0648	21	July 22, 1980
4	0.045	15	April 7-8, 1981
5	0.2077	69	September 24-25, 1981
6	0.1085	36	September 29-30, 1981
7	0.1165	39	September 8-9, 1981
8	0.1068	36	October 8, 1981

NOTES:

* Emission level shown in grams of particulate per kilogram of dry exhaust gas corrected to 50 percent excess air. The number shown above is the average of three (3) sample repetitions as set forth in the U. S. EPA method for particulate testing.

+ The standard for particulate emissions was 0.30 gms/kg corrected to 50 percent excess air set forth in the consent decree and elsewhere. No single sample during the testing program yielded results in excess of the standard.

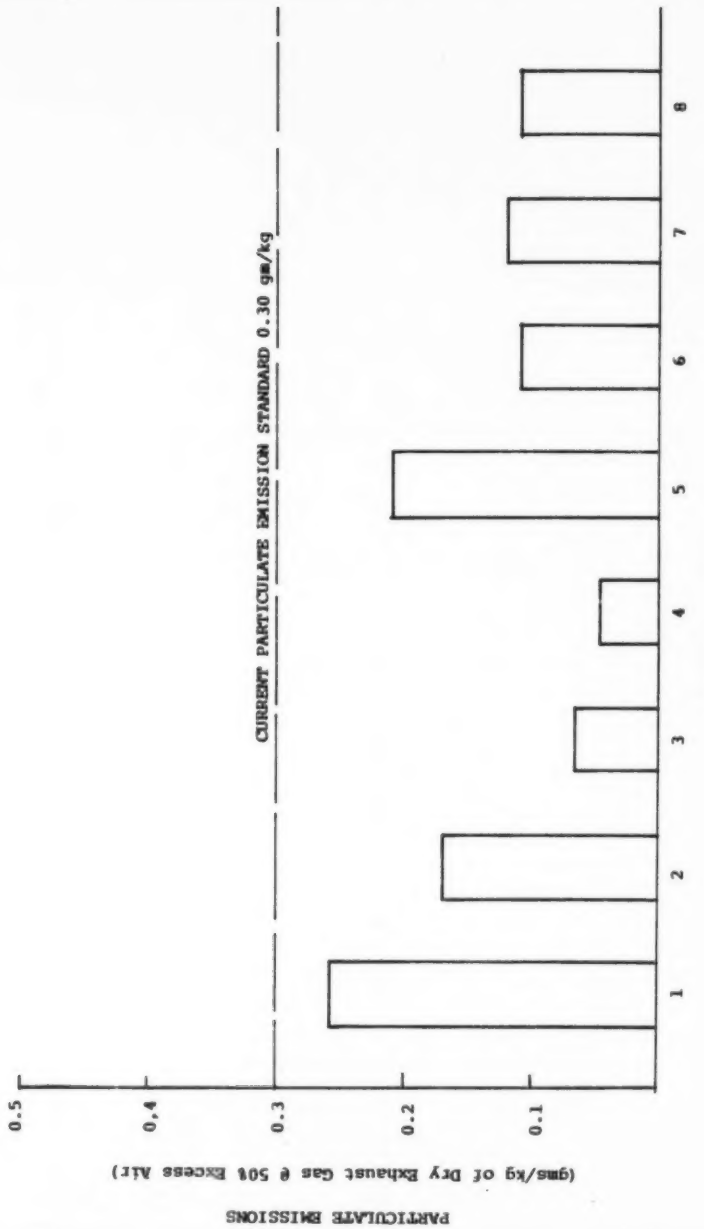

Figure 35. Incinerator Particulate Emissions Compliance Test Results

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1. Verdouw, A. J. and Waltz, E. W., "Demonstration of Waste Sludge Incinerator Fuel Reduction-Pilot Project Report", Indianapolis Center for Advanced Research, Indianapolis, Indiana, 1980, 132 pp, Department of Energy Report (DOE), DOE/CS/20321-1, Contract: AS02-79CS20321). ERDA/32064, NTISDE DE/81030163 (149P)

2. Verdouw, A. J., Waltz, E. W., and Bernhardt, W., "Demonstration of Sludge Incinerator Fuel Reduction", Proceedings of the 53rd Annual Conference of the Water Pollution Control Federation, Las Vegas, Nevada, 1980.

3. Verdouw, A. J., Waltz, E. W., and Bernhardt, W., "Demonstration of Sludge Incinerator Fuel Reduction", Proceedings of the 1980 Municipal and Industrial Sludge Utilization Conference, Alexandria, Virginia, 1980.

APPENDIX

INSTRUMENTATION AND CONTROL SYSTEM COMPONENTS

A.	Sludge Flow Measurement		
	1. Weigh Scales	Tecnetic	WY-10-02-42
	2. Signal Processing Units	Tecnetic	WP
	3. Circular Chart Recorder	Honeywell	AR 15 ADN
B.	Fuel Flow Rate Measurement System		
	1. Flow Rate Meters	Flotron	Model 10E
	2. True Mass Flow Indicators	Flotron	Model 28
	3. Fuel Totalizer	Flotron	Model 23
	4. Fuel Filters	Flotron	90015
C.	Oxygen Analysis System		
	1. Oxygen Analyzer with Temperature Controller and Electronic Read Out (In-situ type with Zirconium oxide cell)	Hays Republic	Oxyprobe A-10007
	2. Flow Meter	Hays Republic	1152-134
	3. Flow Meter Pressure Regulator	Hays Republic	1140-094
D.	Fuel Flow Control System		
	1. Manual Remote Control	Honeywell	53102-14
	2. Diaphragm Actuator	Honeywell	8610107-101-01
	3. Butterfly Valve	North American	1126-K
	4. Pressure Regulator	Honeywell	30358249-5
	5. Heavy Duty Air Filter	Honeywell	30366472-1
E.	Air Flow Control System		
	1. Heavy Duty Control Damper	Ruskin	CDR82-16 inch
	2. Counterbalanced Backdraft Damper	Ruskin	CBSR-MB-20 inch
	3. Diaphragm Actuator	Honeywell	8610107